STUDIES ON THE DIFFERENTIAL FEEDING OF GRASSHOPPERS ON STRAINS OF *ZEA MAYS* (L.)

by

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INTRODUCTION

Severe outbreaks of grasshoppers in the Great Plains area have offered several unusual opportunities for observations on differential feeding of these insects on corn, Zea Mays (L.). Field observations have indicated a need for special methods of controlled infestation in localities where grasshoppers are sporadically abundant as a means of indicating susceptible and resistant strains of open-pollinated corn, inbreds and hybrids.

The phases of the problem of grasshopper resistance in corn are numerous. There have been incidental observations but very few systematic studies on grasshopper resistance in corn. In breeding for insect resistance in plants, as for disease resistance, often much delay is forced upon the worker because of the absence of a natural infestation. To produce artificial infestation of insects is often very expensive, time consuming, and sometimes very difficult.

Plant breeders with the aid of the science of genetics found it possible to transfer many characteristics within species almost at will. For the most part, plant breeders attempt to select those characteristics that are the end result of the combined force exerted by many unidentified factors. As examples of such factors we have disease resistance, quality of fruit, and resistance to drought. More recently wide-spread interest has been shown in breeding for another characteristic of this type - insect resistance.

Insect resistance may be defined as those characteristics which enable a plant to evade, tolerate, or resist the infestation of insects under conditions that would cause greater damage to other plants of the same species. Evasion or escape may be brought about by ecological factors. With the exception of "date of planting" records, there is relatively little data indicating the possibility of resistance introduced by ecological means. The ability of a plant to tolerate the attack of insects is the ability of the plant to continue growth and produce satisfactory yields despite insect infestation. Immunity is a word that has unfortunately been used synonymously with insect resistance. An immune plant may be defined as one which a specific insect will not injure or infest under any condition. There are cases of resistance that approach immunity but no case of actual immunity appears to have been observed or recorded. Host-plant resistance is relative and is measured by comparison with the susceptible or commonly grown plants of the same species. Resistance to insect attack may well vary with the intensity of the insect infestation.

Outstanding differential injury from grasshoppers occurred among strains of corn at the Agronomy Farm at Manhattan, Kansas in 1941. Notes were recorded of the estimated percent defoliation by grasshoppers on more than 200 inbred lines and 700 single and double crosses. With the observations of 1941 as a guide to selection of hybrid strains, a method of controlled infestation was started in the Plant Research Laboratory, Manhattan, Kansas in the winter of 1941 and 1942. These studies were resumed in March, 1946, and continued to August, 1946.

The experiments conducted in the greenhouse were for the purpose of studying grasshopper feeding under controlled conditions, and to determine the following: (1) the agreement between the reaction of inbred lines of corn under artificial conditions and their reaction under field conditions; (2) the differences existing among inbred lines in the transmission of resistance or susceptibility to their hybrids; (3) the effect of nitrogen and phosphorus fertility levels on the relative resistance of two resistant and two susceptible double crosses; (4) and to ascertain, in so far as possible, the value of controlled infestation as an aid in breeding for grasshopper resistance in corn.

REVIEW OF LITERATURE

Parker (42) in a summary of losses has stated that in regions where conditions are favorable for their development, grasshoppers are the farmers' most dangerous insect. Grasshopper damage varies from slight injury during years of ordinary abundance to total destruction of all crops over large areas during extensive outbreaks. Parker gave estimations for the ten year period 1925 to 1934, inclusive, placing the value of crops destroyed in States more heavily infested with grasshoppers at $249,984,727. Although no accurate annual records have been kept, losses were estimated to amount to several million dollars during normal years and far beyond that during outbreaks.

The use of insect-resistant strains of plants to produce satisfactory yields in the presence of insect-infestation is not new. Since the written report in 1792 on the resistance of the wheat variety, Underhill, to attack by the Hessian fly, Phytophaga destructor (Say), the use of insect-resistant or tolerant crops has been advocated as an approach to the insect control problem. In 1869 the discovery of the high degree of resistance of American vines to grape phylloxera, Phylloxera vitifoliae (Fitch), brought about a swift recovery from damage by phylloxera in France once the resistant vines were introduced from America. These early observations and discoveries have been followed by many others. Accessible literature up to 1941 reviewed by Snelling (50) included 567 papers dealing with the subject of host resistance. The literature includes records of resistance in nearly 100 plant species involving over 100 insect species. Resistance of plants to insect attack has been reported on corn and the principal agronomic crops.

Blanchard and Dudley (7) in 1934 were perhaps the first to report a high degree of resistance in some alfalfa varieties and selections to attack by the pea aphid, Macrosiphum pisi (Kalt.). The same year, at Manhattan, Kansas, wide differences in degree of infestation and injury in alfalfa varieties to attack by this insect were recorded. By testing individual plants selected on the basis of having shown definite resistance or susceptibility in field plots, Dahms and Painter (14) have shown that resistance of alfalfa plants to attack by the pea aphid appears to be due to incompatible food relations, the exact nature of which is not known. To date no single plant character has been definitely associated with the resistance of strains of alfalfa to the pea aphid.

Available literature indicates that the main insect pest of sorghums in the United States is the chinch bug, Blissus Leucopterus (Say). Snelling, et al. (52) conducted resistance studies on most of the important and standard varieties of sorghums. They concluded that in general the milos are very susceptible, the feteritas susceptible, and the kafirs and sorgos rather resistant. The results obtained by these workers suggest that resistance is dominant or partially dominant and that the inheritance of chinch bug resistance is complex and is influenced not only by genes directly affecting chinch bug reaction but also by genetic factors controlling such plant characters as earliness, vigor of early growth, character of sheath and others. The difficulty in determining whether the high resistance of F_1 sorghum hybrids is genetic or a result of rapid and heavy plant growth has been shown by Dahms and Martin (13).

The report by Havens (22) in 1792 on the resistance of the wheat variety, Underhill, to attack by the Hessian fly, Phytophaga destructor (Say), has been followed by many papers and reports on differential resistance to this insect. A consideration of the nature of the resistance only will be presented here.

In 1936 Cartwright and Wiebe (10), working with the wheat crosses, Dawson x Poso and Dawson x Big Club, presented data that indicated that the factors for resistance to the Hessian fly are transmitted in accorance with genetic laws. Workers in

Canada (20) found a positive correlation between the height of the wheat and infestation on the 1st of April, about the time that flies begin to emerge and oviposit on winter wheat. In their work on the transference of the resistance to the Hessian fly in Marquillo spring wheat to winter wheats, Painter, et al. (40) have grouped the resistance of Marquillo and Marquillo hybrids into three mechanisms. The primary factor of resistance in Marquillo and its hybrids is the low larval survival of the Hessian fly. The other two factors, which appear more sensitive to environmental conditions than larval survival, are low oviposition and tolerance. The manner in which these resisting factors operate is unknown. The fly resistance derived from Marquillo tends to be recessive, although it appears to be due to more than one factor. Noble and Suneson (37), working in California, confirmed the presence of two factors for resistance to Hessian fly in Dawson wheat. The successful isolation, differentiation, and recombination of the two Dawson factors was demonstrated.

In 1943 Reitz and co-workers (44) presented quantitative evidence which definitely proved that inherent resistance and tolerance to insects and diseases can give a considerable measure of protection to winter wheats of the central Great Plains.

The successful application of the breeding method for control of Hessian fly has most recently been shown by Caldwell, et al. (9). These workers have shown that the Hessian fly-resistant W38 differs from the susceptible wheats by a single gene pair governing resistance. Under field conditions resistance tended to be dominant while under greenhouse conditions it was usually recessive. These authors state:

> Resistance derived from W38 and its hybrid progenies is shown to have two expressions in resistant genotypes, viz. (a) the capacity, under favorable conditions, to suppress the development of Hessian fly larvae with resultant normal plant growth; and (b) the capacity to grow nearly normally and not to show stunting under conditions that prevent the full development of resistance and thus permit infestation to occur.

The work to date on Hessian fly resistance definitely demonstrates that resistance to this insect is transmissible like other plant characters and can readily be included in the breeding program.

Jones (32) made observations indicating marked differences in the reaction of wheat varieties to the chinch bug, *Blissus leucopterus* (Say). The nature of the resistance has not been explained.

Recorded observations (1, 2, 17) indicate the resistance of wheat varieties to the wheat stem maggot, *Meromyza americana* (Fitch). No explanation has been attempted for the resistance of some wheat varieties to attack by this insect.

Observations on differential feeding by grasshoppers on spring wheat have been fairly numerous. In 1936, Clark (11) reported less damage to Ceres wheat than to other varieties grown in North Dakota. From observations at Dickinson, North Dakota, Smith (48) concluded that cereal crops were preferred by grasshoppers in the order: barley, oats, wheat, corn and sorghum. He further indicated a significant positive correlation in wheat varieties between stem rust susceptibility and damage sustained by grasshopper attack and proposed the following explanations for the correlation:

1. Changed chemical content of rusted stems, such as greater percentage sugar.

2. High protein content of rust spores (18.9 percent in one sample) makes them more attractive to hoppers.

3. Softer and more juicy stems of some varieties.

4. Stems broken by rust postules are more easily broken and chewed off.

Swenson (53) indicated from field observations in South Dakota that grasshoppers preferred cereal crops in the order: barley, oats, and wheat. His data showed that certain varieties of wheat and barley were consistant in their respective reaction to attack. From observations on differential feeding of grasshoppers on 41 varieties of wheat, Jacobsen and Farstad (31) concluded there were distinct varietal differences in the number of heads cut off. Hehn (24) showed by contrasting a few varieties of resistant and susceptible spring wheats that the amount of peripheral mechanical tissue in the wheat plant structure in the area immediately below the peduncle appeared to be strongly associated with the feeding of the grasshopper in that area. The above workers explain the resistance to grasshoppers in strains of spring wheat primarily on the basis of certain anatomical and physiological attributes. Studies on the mode of the inheritance of the resistance and the application of genetic principles would in all probability be a much greater aid in selecting strains of wheat resistant to this insect.

Observations on preferential feeding of insects on grass species and strains are available. Hermann and Eslick (25) found significant differences in the susceptibility in the seedling stage of 405 selections out of 28 species of grasses to attack by the grasshopper, Camnula pellucida (Scudd.) and three species of grasshoppers of the genus Melanoplus. The nature of the resistance or its association with any plant character was not indicated. In 1939, Jones (33) reported on several species of grasses belonging to the tribe Hordeae as providing satisfactory hosts for the Hessian fly, Phytophaga destructor (Say). Hayes and Johnston (23) reported on differential reaction of certain grasses to chinch bug attack. Perennial species of grasses native to Kansas having harsh tissues were able to survive the insect injury and showed the most marked ability to recover.

Nearly seventy years ago Riley (45) reported on preferential feeding of grasshoppers on corn and sorghum. The period from 1877 until the development and use of inbred lines of corn came into use was primarily one of observation in respect to insect resistance in corn. With the advent of inbreeding and hybridizing, a new means became available to the investigators searching for some way to combat insect attack.

In 1921 Flint (19) reported on certain open-pollinated varieties of corn that were resistant to, or tolerant of, the attack of the second brood of chinch bugs. Variation in resistance of inbred lines of corn to attack by second brood chinch bugs was first reported in 1934 by Holbert et al. (26).

These workers indicated that some inbred lines carry dominant factors for chinch bug resistance, while other inbred lines carry dominant factors for susceptibility. In Kansas in 1935 Painter, et al. (41) showed that inbred lines of corn existed which transmitted to their progeny a high degree of resistance to second brood chinch bugs.

One of the primary difficulties in controlling pollination in corn has been the corn leaf aphid, _Aphis maidis_ (Fitch). Snelling, et al. (51) presented data indicating great differences in the amount of injury sustained by many yellow and white inbred lines as well as from a sufficient number of single crosses to establish that resistance to this insect is a heritable factor. Huber and Stringfield (28) found that inbred lines of maize and their hybrids exhibit heritable differences in susceptibility to the aphid and that this susceptibility is measurably correlated with susceptibility to _Pyrausta nubilalis_ (Hbm.). The data presented indicates the possibility of reducing injury caused by _Aphis maidis_ through the use of host resistance.

The control of germ plasm made possible by inbred lines of corn was perhaps first used in breeding for resistance to the European corn borer, _Pyrausta nubilalis_ (Hbn.). Marston (35) conducted investigations at Michigan using maize "amargo", an Argentine variety resistant to attack by the European corn borer. A total of 1,934 F_3 and F_4 lines of maize "amargo", Michigan open-pollinated, and inbred lines were subjected to a natural infestation of borers. The readings on the borer damage to the lines indicated that the resistant character of maize "amargo" was in part transmitted to the progeny. Of the nature of the resistance carried by corn borer resistant inbred lines, Patch, et al. (43) have stated that, "The cumulative effect of an undetermined number of multiple factors in inbred lines in producing borer resistance in hybrids is clearly indicated."

The southern corn rootworm, Diabrotica duodecimpunctata (F.), has received some study since the preliminary observations in 1927 by Bigger, et al. (4). The 1927 observations indicated a sharp difference in varieties of corn with reference to injury by the southern corn rootworm. In 1935 and 1937 through 1939, more intensive studies were made. It was found that many double cross hybrids were superior to other double crosses and open-pollinated varieties in their ability to stand erect in the field after severe root pruning by this insect. In 1941 Bigger and his co-workers (5) presented data for inbred lines and single crosses which indicated a differential response by the plants, resistance being heritable. The Indiana inbred line 38-11 was outstanding in its resistance to lodging after attack and transmitted the resistance to hybrids.

Progress has been made in breeding for resistance in corn strains to the corn earworm, Heliothis armigera (Hbn.). Painter and Brunson (39) have obtained data indicating a consistent tendency toward resistance or susceptibility to earworm damage by ears of certain inbred lines of corn. A further example of the development of corn earworm resistant hybrid strains of corn was accomplished at Illinois by Blanchard, et al. (6). These authors stated, "The development and use of resistant hybrids seems to offer the most promising method of materially reducing earworm damage. The data indicate that resistance to the corn earworm is inherited."

In 1931 Hume (29) noted differential feeding of grasshoppers on corn, sorghums, and other crops. He recorded the following observation: "Evidence is presented to show that the injury to dent corn by grasshoppers was greater than to flint corn." Brunson and Painter (8) studied the preferential feeding of grasshoppers on corn strains during the 1936 outbreak in Kansas. They noted outstanding instances of differential injury among corn varieties, top crosses, and hybrids. In one series of 52 hybrids, defoliation ranged from 4.0 percent to 59.8 percent as averages of five randomized replications. The authors stated, "As a rule the varieties and inbred lines of corn showing the greatest resistance originated in areas where grasshoppers are a natural element of the environment." The striking contrasts in defoliation recorded, according to the authors, left little doubt of a genetic basis for the differential injury.

A study has been made concerning the inheritance of resistance to grasshoppers. Horovitz and Marchioni (27) found that maize "amargo" is resistant to grasshopper attack. These authors assumed a single gene difference and presented data to show that susceptibility was dominant and resistance recessive. No morphological characters were found that could be correlated with resistance to grasshoppers. The authors discussed the origin of maize "amargo" connecting it, in the light of the hypothesis of Mangelsdorf and Reeves (34), with the resistance of Tripsacum to the attack of insects. In 1943 Bigger (3) stated that greenhouse studies which were carried on at Illinois during the period 1938-to 40 and not yet published, showed that hoppers of the species Melanoplus differentialis (Thos.) had distinct preference for certain inbred lines when given choice. The observations on preferential feeding of grasshoppers on corn, although not numerous, establish the possibility of breeding strains resistant to this disease.

As the grasshopper is often erroneously considered to be an extremely omnivorous insect, the value of determining resistant lines of corn may be questioned. Nevertheless, it is highly probable that resistant strains of corn can be developed which will be sufficiently undesirable to the grasshopper to force the insect to feed on grasses and forbs. Under conditions such as occurred in South Dakota in 1931 (47) when grasshoppers destroyed almost all vegetation in an area of 30,000 square miles, grasshoppers would likely be forced to attack the resistant crops. The data available regarding specific diets for maximum longevity and fecundity, would indicate that even under such conditions the plant breeders' efforts may not be in vain. The incompatible food relationship would reduce subsequent populations. Adverse effects on the insect life history which result when a resistant variety or species is used have been reported for many insects (14, 15, 30 and 40).

According to Wilbur, et al. (55) in western Kansas even a partial replacement of wheat or barley with sorghums would tend the alleviate the feeding of Melanoplus mexicanus as sorghums provide a less satisfactory food for growth and fecundity. In Arkansas, Sanderson (46) found that the replacement of large acreages of cotton with soybeans resulted in a large increase in populations of M. differentialis. Cotton was unsatisfactory for maintaining populations for rapid growth and high fecundity. Shotwell (47) has indicated that M. differentialis (Thos.) and M. bivittatus (Say) are grasshoppers adapted to areas of cultivated crops and do more damage to corn than to any other species and a lessening in damage to corn was a fair indication of a reduction in the numbers of these two species. A cropping system composed of grasshopper resistant strains of corn might well exert a depressing force on grasshopper populations.

The mistaken belief that all of the different species of grasshoppers eat everything green cannot be maintained. Recent investigations by Isley (30) show that species of north-central Texas grasshoppers, while not necessarily limited to a single host plant, live very successfully and appear to secure all diet needs for their longevity and reproductivity while feeding on a single host plant. He stated that, "Economic entomologists working on the problem of the control of pest species should also investigate the possibility of the eradication of primary host plants as a method of cutting down the longevity and fecundity of such oligaphagous pest species as M. bivittatus and M. differentialis." He further stated "_ _ that food specificity research will contribute to progress in working out the control of pest hoppers."

It is possible that grasshopper control by the use of poison bait might be more effective on grasshoppers which have been feeding on less preferred hybrid combinations of inbred lines. Swingle (54) has indicated tremendous variations in the toxic action of lead arsenate on leaf feeding insects depending on the previous diet.

Available information shows that the nature of specific insect resistance in a specific plant is for the most part due to a number of causes or mechanisms. Snelling (50) has divided the plant characteristics responsible for insect resistance into fifteen categories. Painter (38) has indicated that one or more of three characteristics lie at the basis of most cases of resistance and that these three characteristics are interrelated. These characteristics are antiboisis, preference, and tolerance.

The use of resistant plants as an adjunct in insect control has been advocated by Painter (38). He stated, "Indeed where resistant genes are incorporated into new and improved varieties the commercial use of these resistant varieties may pay additional profit because of the presence of improvements in addition to insect resistance."

The possible contribution of a soil complex and its influence on the plant susceptibility to insect attack has been suggested by some of the literature on host-plant resistance. Observations have been reported in which the nitrogen content of the soil and plant affected the plants' ability to resist attack. Dodd (16) reported that the prickly pear, _Opuntia spp,_ grown on nitrogen deficient soil in Australia was abnormally yellow and contained about one half as much nitrogen as prickly pear growing on richer soil. He found that Cactoblastis cactorum (Berg.) did not survive nearly so well on the yellow prickly pear as on the normal plant, and that when the soil where yellow prickly pear was growing was fertilized C. cactorum increased in numbers. Evans (18) found that the rate of reproduction of the cabbage aphid Brevicoryne brassicae (L.) was positively correlated with the nitrogen content of the host plant, and in particular with the protein content. In Oklahoma, experiments conducted by Dahms and Fenton (12) indicated that the resistance of both resistant and susceptible varieties of sorghums in the majority of cases was increased by the addition of superphosphate (16 percent P_2O_5) and was consistently decreased by the addition of sodium nitrate (16 percent N) in the soil.

Foster and Jeffery (20) in their work with Hessian fly showed that applications of sodium nitrate, superphosphate and a complete fertilizer did not appear to have any significant effect on the yield of heavily infested wheat.

The authors reporting on C. cactorum, the cabbage aphid, and chinch bugs attacking sorghum, have all indicated that an adequate nitrogen supply resulted in an increased insect attack. A report by Mathur (36) in 1941 on field and laboratory observations on the infestation of sugar-cane by Aleurolobus barodensis (Mask.) showed that this insect did not show a positive response to an increased nitrogen supply. The infestation of sugar-cane by the white fly was generally severe when the plants were physiologically starved of nitrogen and was negligible when the nitrogen supply was adequate.

In 1946 Haseman (21) reported on soil fertility investigations that involved the grain aphid, chinch bug, greenhouse thrips, greenhouse white fly, and the Colorado potato beetle. His observations indicated that the thrips and the chinch bug, feeding on corn, are insects naturally adapted to satisfy their nutritional needs by feeding on the nitrogen-starved plants; that the data on the grain aphid indicates that it requires ample nitrogen in its diet; no definite conclusions were drawn on the Colorado potato beetle; and on petunia plants, white flies thrive best on those grown on full nutrients, and in the case of tomatoes, the plants on full nutrients were less attractive.

The literature indicates that each insect has its specific nutritional requirements which seem to vary greatly so far as species of plants are concerned.

The above review of literature is a brief summary of outstanding work in the field of host plant resistance. It is evident that considerable progress has been made; however, in view of potential possibilities of incorporating resistant germ plasm into new varieties of agronomic crops, much remains to be accomplished. The inherent resistance of crop plants to insects is influenced by their adaptation to soil conditions and climatic factors. The effect of soil fertility on insect resistance warrants further study.

MATERIALS AND METHODS

Observations herein reported were made on the Agronomy Farm and in the Plant Research Laboratory, Kansas Agricultural Experiment Station, Manhattan, Kansas. Field observations were made on mature corn plants, whereas seedling plants were used in the greenhouse studies. In estimating percentage defoliation and percent damage on mature and seedling plants respectively, grades from one to ten were used. A grade of one indicated one to ten percent defoliation; a grade of ten 91 to 100 percent defoliation; the eight intervening grades referred to corresponding percentages of defoliation. In seedling plants the phrase "percent damage" was used as the grasshopper injury was not confined to the destruction of the tender portions of the leaf blade.

Field Observations, 1941

The 1941 readings on the percentage of leaf area removed by the grasshoppers on each strain of 89 experimental and commercial hybrids was estimated independently by three observers. The average of the three estimates was used as the individual strain figure. Even though the three observers worked independently, their estimates were very consistent. The mean percentage defoliation recorded by each observer for the 89 strains of corn was as follows: J.L. 39.44, J.N. 38.87, W.F. 39.44, mean 39.25. The remainder of the readings taken under field conditions was estimated by one observer.

Greenhouse Studies, 1942 and 1946

Grasshoppers of the species M. differentialis (Thos.) and M. bivittatus (Say) were used in the 1942 greenhouse studies. Eggs of these two species were collected in the fall of 1941 in the vicinity of Manhattan, Kansas. The 1946 greenhouse studies were limited solely to infestations by the grasshopper M. bivittatus. Eggs of this species were secured from Greeley County as they were not available locally. Hatching of the eggs for both the 1942 and 1946 studies were accomplished in the greenhouse. The nymphs were reared in an 8 x 9 x 12 inch screen cage enclosing the strains of seedling corn.

In each of the experiments conducted in 1942 and 1946 the plants had an average height of ten to twelve inches at the time the grasshoppers were introduced into the cage. In all experiments the period of infestation varied from eight to seventeen days depending on the age and the number of grasshoppers available. The average period of infestation for the three experiments conducted in 1942 was from 12 to 14 days.

In both the 1942 and 1946 studies the entries and the grasshoppers were contained in the screen cage shown in Plate I. The cage used for the controlled infestations was 24 inches wide x 25 inches high x 93½ inches long. The three types of damage sustained by entries under greenhouse conditions are exhibited by Plate II. The damage consisted of the destruction of the tender portions of the leaf blade, the destruction of the midrib in some entries (pot 2) and in other entries the grasshoppers cut off the entire stem. Each type of injury was taken into consideration

EXPLANATION OF PLATE I

The screened cage used for controlled infestation of grasshoppers on corn seedlings under greenhouse conditions.

Plate I

EXPLANATION OF PLATE II

Relative defoliation displayed by seedling plants under greenhouse conditions. Note the slightly injured plants in pot 1 as compared to plants in pots 3 and 4. Pots 1 through 4 occurred in the fourth replication of the nitrogen fertility level tests in 1946. The hybrids and percent damage recorded were as follows: 1 K1585 (13 percent), 2 K2234 (60 percent), 3 KIH 38 (87 percent), and 4 US 35 (90 percent).

Plate II

in evaluating percent damage. A discussion of the entries and experimental designs used follows.

Inheritance Studies. Four inbred lines were selected for this study in 1942 on the basis of their reaction under field conditions. The lines were Hy and L317, susceptible; 38-11, intermediate in its reaction; and US 540, resistant. Included in the experiment were six single crosses, three double crosses, two back crosses and one sweet corn entry as a check. The 16 entries were replicated three times in randomized order. Five inch pots were used and each had a uniform stand of four plants. Approximately 80 adult grasshoppers of the species *M. differentialis* and *M. bivittatus* were used in this experiment in equal numbers. The percent damage sustained by entries was estimated by one observer.

In 1946 twelve strains of inbred corn were grown in four inch pots, four plants per pot. Each strain was replicated four times in randomized order. The 12 inbred strains used for the study are component parts of the following four double crosses: K2234, K1585, US 35, and KIH 38. A total of 120 second to third instar grasshoppers *M. bivittatus* were introduced into the screen cage enclosing the inbred lines. The percent damage to the inbreds was estimated independently by two observers for each pot. The average of the two estimates was used as the individual pot figure. With four replications the final estimate per inbred strain represented a mean of eight separate estimates. The mean percentage damage estimated for the 48 pots of inbreds was as follows: J.A.N. - 52.50, L.A.T. - 52.08, mean 52.29.

The 1946 studies included an experiment of 21 single crosses. The entries were grown in four inch pots, two plants per pot, and were replicated four times in randomized order. All combinations of inbred strains in a double cross, i.e., K2234, determined the single cross combinations used in this study. For each of the four double crosses, K2234 and K1585, resistant under field conditions; and US 35 and KIH 38, susceptible under field conditions, there were two parental and four non-parental single crosses. As three of the single crosses were the same for two of the double crosses a total of 21 single crosses were subjected to infestation. The single crosses were infested by 114 fourth to fifth instar grasshoppers *M. bivittatus.* Two observers estimated the damage to each pot. For the 84 pots of single crosses the following mean estimations were recorded: J.A.N. - 54.88, L.A.T. - 57.02, and mean 55.95.

The four double crosses, K2234, K1585, US 35 and KIH 38, were subjected to infestation in 1946, using four four-inch pots per replication and a uniform stand of four plants per pot. The four entries appeared in five replications in randomized order. The experiment involving the above listed double crosses was repeated. The infestation from May 10 to May 23, 1946 utilized 60 fourth to fifty instar grasshoppers and from June 8 to June 23, 1946 a total of 30 adult grasshoppers were used. A third experiment employed the same experimental design as described above except that "amargo" maize was substituted for K2234. This experiment was infested by 35 adult grasshoppers. Percent damage resulting from grasshopper feeding was estimated on an individual plant basis by one observer. The average of the four plants occurring in a pot was used as the pot figure.

Fertility Level Studies. Four double crosses, K2234 and K2182, resistant to grasshopper feeding under field conditions, and US 35 and DeKalb 816, susceptible to grasshopper feeding under field conditions, were used in the nitrogen and phosphorus fertility level studies in 1942. The levels included a check, 300, 600 and 900 pound applications of NH_4NO_3 (32.5 percent N), and a check, 225, 450 and 675 pound applications of superphosphate (43 percent P_2O_5). Each entry and each level of nitrogen or phosphorus, including the check, appeared in combination once in a replication.

Each of the experiments had 16 entries which were replicated three times in randomized order. Five inch pots were used and each pot had a uniform stand of four plants. Application of the NH_4NO_3 and superphosphate was made when the corn plants were four to six inches in height. The fertilizers were applied in circular fashion near the edge of the pot and about one inch below the soil surface. Approximately 80 adult grasshoppers of the species M. differentialis and M. bivittatus were used in each experiment in equal numbers. The percent damage sustained by entries in each of the two fertility studies was estimated by one observer on a pot basis.

Nitrogen fertility levels, applied in 1946, were the same as those used in 1942. Superphosphate (20 percent P_2O_5) levels for 1946 included a check, 485, 975 and 1455 pound applications. The NH_4NO_3 was applied to each pot in solution and the superphosphate was placed between the plants down deep enough in the soil to be in the root zone. In addition to the straight nitrogen and phosphorus fertility level studies, an experiment was designed using a check, 600 pound application of NH_4NO_3, 975 pound application of superphosphate and 600 pounds NH_4NO_3 plus 975 pounds superphosphate in combination. A second experiment utilizing nitrogen, phosphorus and nitrogen plus phosphorus was the same as the above except that 485 pound applications of superphosphate were substituted for the 970 pound applications of superphosphate. The four double crosses, K2234 and K1585, resistant; and US 35 and KIH 38, susceptible, were used in the fertility level studies in 1946. The hybrids K2182, resistant, and DeKalb 816, susceptible, which were used in the 1942 studies were not available for further experiments. Each of the experiments had 16 entries which were replicated four times in randomized order. Four inch pots were used and each pot had a uniform stand of three plants. The fertility level entries in 1946 were infested by the following numbers of M. bivittatus: nitrogen levels, 45 adult and 80 third instar grasshoppers; phosphorus levels, 51 adults and 90 third to fourth instar grasshoppers on the first experiment and 90 adults on the second experiment; the nitrogen, phosphorus (975# Superphosphate), and nitrogen plus phosphorus experiment, 45 adult and 80 fourth to fifth instar grasshoppers; and the nitrogen, phosphorus (485# superphosphate) and nitrogen plus phosphorus experiment, 90 adult grasshoppers. Percent damage sustained by the entries in the 1946 fertility level studies was estimated on an individual plant basis by one observer. The mean percent damage of the plants growing in one pot was used as the pot figure.

All data were treated statistically. The methods of calculating the analysis of variance and correlation coefficients were taken from Snedecor (49).

EXPERIMENTAL DATA

Field Observations

The grasshoppers infesting the corn test plots on the Agronomy Farm in 1941 were mostly Melanoplus differentialis (Thos.) and M. bivittatus (Say). In one planting of 89 commercial and promising experimental hybrids, percentage of leaf surface removed ranged from 10 to nearly 100 percent. Plate III indicates the extremes in percent of leaf area destroyed. For the most part grasshopper infestation was not severe. The readings were of particular value in serving as a basis for selection of material for the greenhouse studies.

Table 1 gives the frequency distribution of the percent defoliation of the 89 hybrids and varieties. The planting of 89 strains was parallel to an alfalfa field. Infestation was not uniform; the plots occurring in the center portion of the replication had a much higher average percentage of defoliation than those on either end. Because of the unequal distribution of grasshoppers, a five point moving average was used to minimize the effect. Table 1 is based on corrected percent of defoliation.

EXPLANATION OF PLATE III

Differences in resistance to grasshoppers of two double crosses under field conditions. The resistant hybrid (left) is Kansas 2234 while the susceptible strain is US 35 (right).

Plate III

It is apparent from the mean pollen shedding date and mean ear height that the earlier lines were most susceptible. The correlation coefficients between percent defoliation and ear height, percent defoliation and pollen shedding date, and ear height and pollen shedding date were -0.3979, -0.5667, and +0.6748, respectively, with "r" at the 1% level equal to ±.272. A multiple correlation coefficient (R) of +0.5669 suggests that ear height and pollen shedding date were very strongly correlated and were concurrent phenomena. Since "R" is nearly the same as -0.5667, no advantage is to be gained by the multiple regression. Pollen shedding date alone can be used as the independent variate. Ear height contributes little additional information.

In spite of the high negative correlations found between percent defoliation and the two variates, ear height and pollen

Table 2. Summary of the relative resistance to grasshoppers of 10 midseason yellow inbred lines in 43 of the 45 possible combinations among them, Manhattan, Kansas, 1941. Infested by *M. bivittatus* and *M. differentialis.* (Tested in Mature stage.)

Line	Percentage of leaf surface removed by grasshoppers									
	Ill Hy	Ia L317	Ind WF9	US 187-2	Oh 07	Ia 198	Ia Kr (Osf	Ill 5120	US 540	Ind 38-11
Ill Hy		60	30	60	20	30	50	60	20	60
Ia L317	60		20	20	30	50	40	30	20	20
Ind WF9	30	20		20	20	20	30	30	20	40
US 187-2	60	20	20		20	40	--	40	20	30
Oh 07	20	30	20	20		20	20	20	--	20
Ia 198	30	50	20	40	20		40	30	10	20
Ia Kr (Osf)	50	40	30	--	20	40		30	40	10
Ill 5120	60	30	30	40	20	30	30		20	20
US 540	20	20	20	20	--	10	40	20		30
Ind 38-11	60	20	40	30	20	20	10	20	30	
Mean	43.3	32.2	25.6	31.2	21.2	26.7	32.5	31.1	22.5	27.8

shedding date, it is doubtful that these values should be considered a reliable index of the relative resistance among the strains of corn observed. Maturity may have been an influencing factor in enabling the resistant plants to escape injury. It is more likely, however, that the high negative correlations were a coincidence resulting from two conditions. First, the more resistant strains contained inbred lines which were selected from Kansas open-pollinated varieties having late maturity and a high degree of grasshopper resistance. Second, many of the susceptible hybrids had essentially the same component inbreds in their makeup as US 13 and US 35. These two strains showed a high degree of susceptibility and early maturity under Kansas conditions.

Data on four groups of single crosses are given in Tables 2 through 5. Four replications of each group were planted at various locations in Kansas. Infestation occurred only at the Agronomy Farm, Manhattan, Kansas. As percent defoliation readings were taken on only one replication of each group of single crosses, it was not possible to subject the data to analysis of variance.

The extreme range of defoliation for the single crosses observed varied from 10 to 60 percent. The two groups of single crosses listed in Tables 3 and 5 were grown in adjacent plots and should have had equal infestation. The data indicate this was not the case. It is to be noted that all inbred lines listed in Table 5 are selections from the open-pollinated variety, Pride of Saline. Observations on 89 double crosses and varieties (Table 1) indicated that Pride of Saline was resistant to grasshopper attack. This variety is adapted to areas where occasional severe grasshopper outbreaks have been experienced. It would seem reasonable to assume that natural selection intensified resistance to grasshoppers in the variety Pride of Saline and that this resistance was retained in the inbred lines selected from it.

Table 3. Summary of the relative resistance to grasshoppers of 11 yellow inbred lines in the 55 possible combinations among them, Manhattan, Kansas, 1941. Infested by *M. bivittatus* and *M. differentialis*. (Tested in mature stage.)

Line	Percentage of leaf surface removed by grasshoppers										
	K 126	K 130	K 148	K 151	K 155	K 159	K 167	K 168	K 201C	Ind 38-11	Ia Kr (Osf)
K 126		20	20	10	20	20	10	10	10	10	10
K 130	20		30	30	30	30	20	30	10	20	20
K 148	20	30		10	20	30	10	10	20	20	10
K 151	10	30	10		20	30	10	10	20	10	20
K 155	20	30	20	20		40	20	10	10	20	20
K 159	20	30	30	30	40		10	40	30	20	40
K 167	10	20	10	10	20	10		10	10	20	20
K 168	10	30	10	10	10	40	10		10	10	20
K 201C	10	10	20	20	10	30	10	10		20	30
Ind 38-11	10	20	20	10	20	20	20	10	20		20
Ia Kr (Osf)	10	20	10	20	20	40	20	20	30	20	
Mean	14.0	24.0	18.0	17.0	21.0	29.0	14.0	16.0	17.0	17.0	21.0

It is of interest to note in Table 2 that Hy was most susceptible and US 540 and Oh 07 most resistant. Oh 07 is a selection out of the cross US 540 x Ill L. Apparently the resistance carried by US 540 was transmitted to the selection Oh 07. The single crosses Oh 07 x Hy and US 540 x Hy tended to be resistant, suggesting that the resistance carried by US 540 and Oh 07 was dominant and the susceptibility carried by Hy was recessive. Table 2 indicates that the inbreds WF9 and 38-11 both transmitted an intermediate grasshopper reaction under field conditions. Greenhouse data to be presented later will show that these two lines reacted much differently when tested in the seedling stage under controlled infestations.

The data given in Table 4 shows a striking difference between the inbreds Ky 27 and Ind 33-16, in their reaction when used in single cross combination. Single crosses in which Ky 27 was used as a parent had a mean reading of 15.6 percent as compared to 34.4 percent for the single crosses in which Ind 33-16 was used as a parent. A resistant reaction was obtained for the cross Ky 27 x Ind 33-16 indicating that susceptibility transmitted by Ind 33-16 was not dominant.

Even though infestation of the single crosses by grasshoppers was light the summarized data give an indication of the relative resistance of the inbreds involved in the crosses. It is apparent that hereditary differences in resistance to grasshoppers occurred among the inbred lines listed in Tables 2, 3, 4, and 5. These lines occur in many of the promising experimental hybrids as well as being component parts of commercial hybrids. The single cross data presented should be of particular value in predicting the relative resistance of double cross combinations.

Table 4. Summary of the relative resistance to grasshoppers of the 10 late white inbred lines in the 45 possible combinations among them, Manhattan, Kansas, 1941. Infested by M. *bivittatus* and M. *differentialis*. (Tested in mature stage.)

Line	Percent of leaf surface removed by grasshoppers									
	Mo 7 Ra	Ky 27	Ky 56	Tenn 18C	Tenn 85A	Ind 33-16	K 55	K 64	US 11b	US 23
Mo 7 Ra		10	30	30	20	40	40	20	20	20
Ky 27	10		10	10	20	20	20	20	20	10
Ky 56	30	10		20	30	50	30	20	20	20
Tenn 18C	30	10	20		30	40	30	20	40	20
Tenn 85A	20	20	30	30		30	20	20	20	20
Ind 33-16	40	20	50	40	30		40	30	20	40
K 55	40	20	30	30	20	40		30	30	20
K 64	20	20	20	20	20	30	30		30	20
US 11b	20	20	20	40	20	20	30	30		20
US 23	20	10	20	20	20	40	20	20	20	
Mean	25.6	15.6	25.6	26.7	23.3	34.4	28.9	23.3	24.4	21.1

Table 5. Summary of the relative resistance to grasshoppers of 10 Kansas white inbred lines in 38 of the 45 possible combinations among them, Manhattan, Kansas, 1941. Infested by *M. bivittatus* and *M. differentialis.* (Tested in mature stage.)

	Percent of leaf surface removed by grasshoppers									
Line	K 8	K 10	K 14	K 17	K 19	K 41	K 55	K 60	K 61	K 64
K 8		20		10	10		10	10	20	20
K 10	20		20		10	10	10	30	10	20
K 14		20			10		10	10		
K 17	10				10	10	10	10	10	10
K 19	10	10	10	10		10	10	10	10	10
K 41		10		10	10		10	10	10	10
K 55	10	10	10	10	10	10		10	20	10
K 60	10	30	10	10	10	10	10		10	20
K 61	20	10		10	10	10	20	10		20
K 64	20	20		10	10	10	10	20	20	
Mean	14.3	16.3	12.5	10.0	10.0	10.0	11.0	13.0	13.8	15.0

Greenhouse Inheritance Studies

Data on the differences in resistance of four inbred lines and their reaction in single cross, double cross, and backcross combinations are given in Table 6 and the analysis of variance in Table 7. The differences between entries were highly significant. An interesting result was obtained from the two backcrosses. The data on the inbred lines indicated that 38-11 was much more resistant than L317. A cross involving these two lines was resistant in reaction. The grasshoppers caused 57 percent damage when the single cross was backcrossed to 38-11 and 83 percent damage when the single cross was backcrossed to L317. The preliminary experiment on the grasshopper reaction of seedling corn plants under greenhouse conditions indicates that 38-11 transmits a resistant reaction and L317 a susceptible reaction.

One would expect the backcross (38-11 x L317) x 38-11 to have a lower reading or to be as resistant as the cross 38-11 x L317. The cross (38-11 x L317) x 38-11 had a reading of 57 percent damage as compared to a 43 percent damage reading for 38-11 x L317. It is possible that the difference existing between these two crosses may have been due to chance alone.

The data presented in Table 6 suggest that the susceptibility carried by Hy tended to be dominant and the susceptibility carried by L317 recessive. Further data on the reaction of Hy and L317 under greenhouse conditions are presented in Tables 8, 10, 12, 13, and 15. It should be noted that the double cross K1714 was resistant and that when the two resistant inbreds 38-11

Table 6. Differences in resistance to grasshoppers of 4 inbred lines, 6 single crosses, 3 double crosses and 2 backcrosses of dent corn and 1 entry of sweet corn, Manhattan, Kansas, 1942. Subjected to *M. bivittatus* and *M. differentialis.* (Tested in seedling stage.)

Entry	Estimated damage (percent)
Inbred Lines	
Hy	73
38-11	50
L317	73
US 540	70
Mean	66
Single Crosses	
Hy x L317	67
x 38-11	63
x Oh 07	73
L317 x 38-11	43
x Oh 07	57
38-11 x Oh 07	43
Mean	58
Double Crosses	
K1638 (38-11 x WF9) x (Hy x L317)	80
K1712 (L317 x Oh 07) x (38-11 x I159L1)	70
K1714 (38-11 x WF9) x (L317 x Oh 07)	53
Mean	68
Backcrosses	
(38-11 x L317) x 38-11	57
(38-11 x L317) x L317	83
Mean	70
Sweet Corn	23
Mean (all entries)	60

Table 7. Analysis of variance of data in Table 6.

Source of variation	D/F	F value
Entries	15	9.27**
Replications	2	3.5
Error	30	2.1

**Highly significant

Table 8. Estimated percentage damage of 12 inbred strains of corn tested in seedling stage at Manhattan, Kansas, 1946. Subjected to M. bivittatus.

Entry	Average height (Centimeters)	Estimated damage (percent) Replication 1	2	3	4	Mean
K4	26	40	25	15	20	25
38-11	37	60	30	30	20	35
R4	40	30	30	35	45	35
K201	29	65	25	50	35	44
K55	32	55	40	35	55	46
K63	30	75	60	40	20	49
K41	37	60	35	80	45	55
WF9	34	75	65	30	65	59
Hy	28	100	25	65	55	61
L317	25	80	40	80	45	61
K64	38	85	70	70	90	79
K155	30	85	90	50	90	79
Mean	32	68	45	48	49	52

Table 9. Analysis of variance of data in Table 8.

Source of variation	D/F	Sum of squares	Mean square	F value
Entries	11	12,297.92	1,117.99	4.30**
Replications	3	3,827.09	1,275.70	4.91*
Error	33	8,572.91	259.79	
Total	47	24,697.92		

*Significant
**Highly Significant

and Oh 07 were combined a resistant single cross was obtained. It is recognized that the data in Table 6 are of preliminary nature and inadequate for drawing conclusions.

The percent damage to the twelve inbred lines is shown in Table 8 and the analysis of variance indicates the differences between inbreds, with respect to grasshopper damage, were highly significant in spite of the wide range in percent damage from one replication to the next for a particular inbred. There was a significant difference between replications. This difference was due to the total difference in percent damage existing in replication 1 as compared to replications 2, 3, and 4. Replications 2, 3, and 4 were relatively uniform. The grasshoppers had a tendency to mass and group on the end of the cage where replication 1 was located. Thus replication 1 was subjected to more frequent feedings than the other three replications.

Table 10 shows the percent damage to the single crosses used in this study. The analysis of variance in Table 11 shows there was a significant difference between single crosses with respect to percent damage by grasshoppers. Statistically, the difference was not too strong because of the variation in percent damage between replications for a particular single cross. A mean square nearly equal to the mean square for error indicates a fairly uniform amount of feeding on each of the four replications.

The inbred data (Table 8) indicated that K4, R4, and 38-11 were resistant. One would assume that single crosses involving these three strains would be resistant to grasshopper attack. A reading of 50 percent damage was obtained for 38-11 x K4, and 48

Table 10. Estimated percentage damage of 21 single cross strains of corn tested in seedling stage at Manhattan, Kansas, 1946. Subjected to M. bivittatus.

Entry	Average height (Centimeters)	Estimated damage (percent) Replication 1	2	3	4	Mean
K41 x K55	26	50	35	30	10	31
38-11 x Hy	32	70	25	45	20	40
K155 x 38-11	33	30	30	55	65	45
L317 x R4	24	30	75	25	60	48
38-11 x R4	29	25	55	65	45	48
K201 x 38-11	32	65	30	65	35	49
K4 x 38-11	31	60	30	40	70	50
K41 x K63	35	65	55	50	35	51
K55 x K64	28	65	65	50	25	51
K155 x K4	27	40	45	90	30	51
Hy x R4	17	60	70	50	25	51
L317 x 38-11	31	55	45	50	60	53
K63 x K64	35	55	40	60	70	56
K155 x K201	29	50	75	70	40	59
K4 x K201	30	85	50	40	65	60
WF9 x R4	29	60	70	75	60	66
K63 x K55	27	70	75	65	60	68
WF9 x 38-11	37	40	60	95	85	70
K41 x K64	32	65	75	90	55	71
L317 x Hy	31	80	70	60	85	74
WF9 x Hy	38	80	65	100	80	81
Mean	30	57	54	60	51	56

Table 11. Analysis of variance of data in Table 10.

Source of variation	D/F	Sum of squares	Mean square	F value
Entries	20	11,866.67	593.33	1.958*
Replications	3	946.48	215.49	1.041
Error	60	18,178.52	302.98	
Total	83	30,991.67		

*Significant

percent damage recorded for 38-11 x R4. The cross K4 x R4 was not tested. The two single crosses involving the above three inbred lines were resistant to intermediate in their reaction to grasshopper feeding. Although the transmission of grasshopper resistance by K4, R4, and 38-11 to the two single crosses was not cumulative, the readings for the hybrids were essentially the same suggesting in this case that K4 and R4 were equally influenced by 38-11.

When K41 and K55 were tested in single cross combination the result was a resistant reaction to grasshopper damage even though the inbreds were intermediate in their reaction (Table 8.) The response of the hybrid K41 x K55 can perhaps best be explained on the assumption of complementary factors contributed by the two parents. However, the data presented here may be inadequate for such a conclusion.

Table 12 summarizes the relative resistance of K155, K201, K4, and 38-11 when used in single cross combinations. The mean percent damage for each of the four inbreds shows little difference in relative resistance suggesting that these lines

Table 12. Summary of the relative resistance of 4 yellow inbred lines used in single cross combinations.

Line	Percent damage by grasshoppers: K155	K201	K4	38-11	Mean	Percent damage to inbred
K155	--	59	51	45	52	79
K201	59	--	60	49	56	44
K4	51	60	--	50	54	25
38-11	45	49	50	--	48	35

are resistant to intermediate in their expression to grasshopper damage when used in single cross combinations. The strain 38-11 had a mean of 48 percent injury demonstrating that it was more resistant than K155, K201, and K4. A graphical representation of the data in Table 12 shown in Plate IV, Fig. 1, bears out this fact.

A summary of the relative resistance of 38-11, WF9, Hy, R4, and L317 when tested in all possible single cross combinations is shown in Table 13. Examination of the mean percent damage for

Table 13. Summary of the relative resistance of 5 yellow inbred lines used in single cross combinations. The cross L317 x WF9 was not tested.

Line	Percent damage by grasshoppers					Mean	Percent damage to inbred
	38-11	WF9	Hy	R4	L317		
38-11	--	70	40	48	53	53	35
WF9	70	--	81	66	--	72	59
Hy	40	81	--	51	74	62	61
R4	48	66	51	--	48	53	35
L317	53	--	74	48	--	58	61

each inbred shows that 38-11 and R4 were resistant and WF9, Hy, and L317 susceptible. Figures 1, 2, and 3 of Plate IV further emphasize that 38-11 and R4 were resistant. It is to be noted that the hybrid Hy x 38-11 is resistant (Table 10). This may well have been an error as the cross Hy x R4 reacted in an intermediate manner. The data in Table 13 suggest that the susceptibility carried by WF9 was dominant, whereas the susceptibility derived from L317 and Hy tended to be recessive. The assumption that the crosses involving WF9 were uniformly susceptible and that Hy tended to be recessive is borne out by Fig. 4 and 5 of

Plate V. The combination of the two susceptible lines, Hy and WF9, produced a cumulative effect for susceptibility. The two susceptible lines L317 and Hy, when combined, reacted in a similar fashion (Table 10).

The results of the single cross combinations involving the four white inbred lines, K41, K55, K63, and K64 are presented in Table 14. The reaction of K41 and K55, when combined, has been

Table 14. Summary of the relative resistance of 4 white inbred lines used in single cross combination.

Line	Percent damage by grasshoppers: K41	K55	K63	K64	Mean	Percent damage to inbred
K41	--	31	51	71	51	55
K55	31	--	68	51	50	46
K63	51	68	--	56	58	49
K64	71	51	56	--	59	79

discussed. A 51 percent damage reading for K64 x K55 is low as compared to expected results and the reading of 68 percent injury to the cross K63 x K55 is high as compared to expected results. However, these differences from the expected may well be within the realm of experimental error.

The data in Table 12, 13, and 14 indicate that marked differences occurred among the strains in the transmission of resistance or susceptibility to their hybrids. Single crosses involving R4 and 38-11 tended to be resistant, except for the combination with WF9. The crosses involving WF9 were uniformly susceptible. The lines K4, K155, and K64 apparently had relatively little influence upon their hybrids. A comparison of the relative resistance of the inbred lines in Tables 12, 13, and 14,

EXPLANATION OF PLATE IV.

A graphical illustration of the percent damage to single cross combinations given in Tables 12 and 13 compared to percent damage to single crosses involving 38-11 and R4. The black bar represents the average for two single crosses in each case and the plain bar the percent damage to the single cross typed thereon. Each inbred listed was tested in three single cross combinations (L317 was not used in this comparison). For instance, in Fig. 1, K155 x K4 and K155 x K201 had an average reading of 55 percent as compared to 45 percent for K155 x 38-11; K4 x K201 and K4 x K155 had an average reading of 55.5 percent as compared to 50 percent for K4 x 38-11; and K201 x K4 and K201 x K155 had an average reading of 59.5 percent as compared to 49 percent for K201 x 38-11.

Fig. 1. Relative resistance of single cross combinations involving 38-11 compared to single cross combinations between K155, K4 and K201.

Fig. 2. Relative resistance of single cross combinations involving 38-11 compared to single cross combinations between R4, Hy and WF9.

Fig. 3. Relative resistance of single cross combinations involving R4 compared to single cross combinations between 38-11, Hy and WF9.

PLATE IV

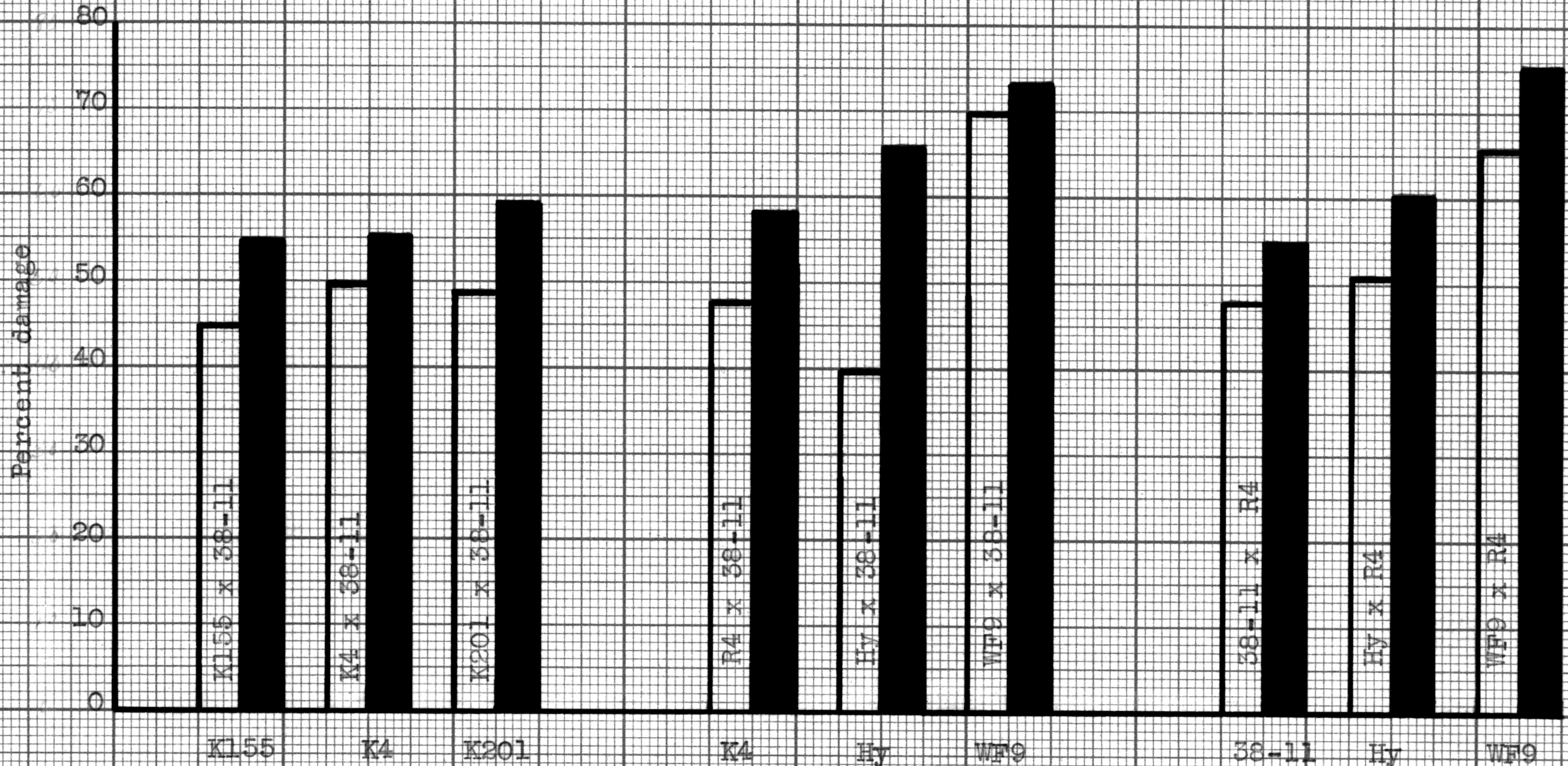

Fig. 1 Fig. 2 Fig. 3

EXPLANATION OF PLATE V.

A graphical illustration of the percent damage to single cross combinations presented in Table 13 compared to percent damage to single crosses involving WF9 and Hy (See explanation of Plate IV.).

Fig. 4. The susceptible strain WF9 compared to the susceptible strain Hy and the resistant strains 38-11 and R4.

Fig. 5. The strain Hy compared to WF9, 38-11, and R4.

PLATE V

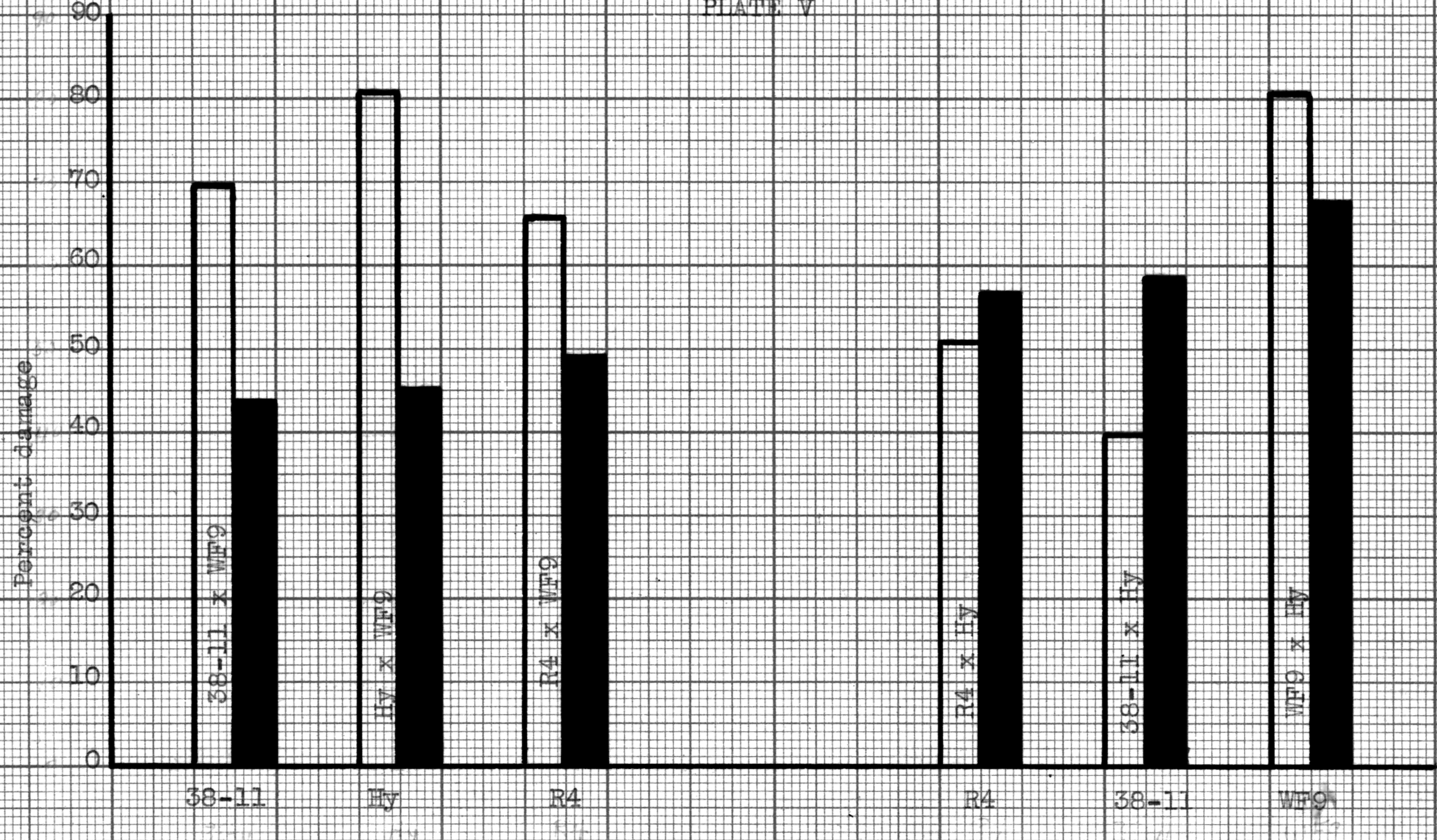

Fig. 4

Fig. 5

when used in hybrid combination, with the percent damage to the individual inbred, indicates, without question, that resistance is inherited. In general, the grasshopper reaction of the inbred, when used in hybrid combination, closely paralleled the percent damage recorded for the inbred.

A comparison of the grasshopper reaction of inbred lines under field and greenhouse conditions is given in Table 15. The field observations were confined to the reaction of the inbred line in single and top cross combination, whereas inbred and single cross data were used to determine the reaction under controlled infestation.

Even though the number of observations used for the summary in Table 15 was limited, the reaction of the inbred lines under the two conditions was in very close agreement. The two strains, 38-11 and WF9, reacted in a much more definite manner when subjected to controlled infestation. The discrepancy that existed when the lines K201, K55, K41, K64 and K155 were contrasted may have been due to the field observations in that a lesser degree of infestation was experienced and relative readings were determined by using a larger number of inbred lines or to stage of growth when infested.

Percent damage to the four double crosses, K2234, K1585, US 35 and KIH 38 are given in Tables 16 and 18. The analysis of variance for the data presented in Table 16 is shown in Table 17 The differences obtained for entries were not significant. Nevertheless, K1585 had a much lower average reading than the other three double crosses. A mean of 66 percent damage for

Table 15. Summary of resistance of inbred lines to grasshoppers under field and green- house conditions.

Inbred line	Field observations: Insect reaction	Field observations: Number of observations	Field observations: Inbred line or in hybrid combination	Greenhouse observations: Insect reaction	Greenhouse observations: Number of observations	Greenhouse observations: Inbred line or in hybrid combination
K4	1/			Resistant	1 year	Inbred Single cross
38-11	Resistant to intermediate	1 year	Single cross	Resistant	2 years	Inbred (2 yrs.) Single cross (2 yrs.)
R4	Resistant	1 year	Top cross 2/	Resistant	1 year	Inbred Single cross
K201	Resistant to intermediate	1 year	Single cross	Intermediate	1 year	Inbred Single cross
K55	Intermediate	1 year	Single cross	Resistant to intermediate	1 year	Inbred Single cross
K63	1/			Intermediate	1 year	Inbred Single cross
K41	Resistant	1 year	Single cross	Resistant to intermediate	1 year	Inbred Single cross
WF9	Intermediate to susceptible	2 years	Single cross (1 yr.) Top cross (1 yr.)	Susceptible	1 year	Inbred Single cross
Hy	Susceptible	2 years	Single cross (1 yr.) Top cross (1 yr.)	Susceptible	2 years	Inbred (2 yrs.) Single cross (2 yrs.)
L317	Susceptible	2 years	Single cross (1 yr.) Top cross (1 yr.)	Susceptible	2 years	Inbred (2 yrs.) Single cross (2 yrs.)
K64	Intermediate	1 year	Single cross	Intermediate to susceptible	1 year	Inbred Single cross
K155	Intermediate	1 year	Single cross	Intermediate to susceptible	1 year	Inbred Single cross

1/ No field results available
2/ Top cross data taken from Brunson and Painter (8).

all entries was recorded. It is probable that feeding had advanced to a stage where the grasshoppers were forced to feed on the more resistant hybrids.

Data on a second experiment using the above listed double crosses is shown in Table 18 and the analysis of variance in Tables 19 and 20. The differences between entries were significant. One would suspect that the significant F value for entries is attributable largely to the lower readings obtained for K1585. Analysis of variance designed to contrast K1585 with K2234, US 35 and KIH 38 gave a highly significant difference between these two groups.

Table 16. Estimated percentage damage of 4 double crosses tested in seedling stage at Manhattan, Kansas, 1946. Subjected to *M. bivittatus.*

Replication	Percent damage: Kansas 2234	Kansas 1585	US 35	KIH 38	Mean
1	50	50	65	65	58
2	55	25	80	70	58
3	80	50	70	60	65
4	70	75	80	90	79
5	90	55	60	80	71
Mean	69	51	71	73	66

Table 17. Analysis of variance of data in Table 15.

Source of variation	D/F	Sum of squares	Mean square	F value
Entries	3	1,540.00	513.33	3.16 1/
Replication	4	1,342.50	335.63	2.07
Error	12	1,947.50	162.29	
Total	19	4,830.00		

1/ Not significant

The mean percent damage of the four non-parental single crosses from the four lines used in each double cross were used to estimate the probable performance of the double cross. No consistent relationship was obtained for the reaction of the double cross and the predicted performance. The mean percent damage readings for the four non-parental single crosses are presented in Table 21. As will be shown later, K2234, in nearly all tests conducted, reacted in a resistant manner. The hybrid US 35 was susceptible in all cases. The lack of agreement between the predicted percent damage and actual percent damage may have been due to the complementary cumulative factors for resistance expressed by the inbred lines used in the parental

Table 18. Estimated percentage damage of 4 double crosses test-in seedling stage at Manhattan, Kansas, 1946. Subjected to *M. bivittatus.*

Replication	Percent damage: Kansas 2234	Kansas 1585	US 35	KIH 38	Mean
1	35	20	47	57	40
2	40	40	47	25	38
3	68	20	27	43	40
4	43	17	77	58	49
5	68	20	75	73	59
Mean	51	24	55	51	45

Table 19. Analysis of variance of data in Table 17.

Source of variation	D/F	Sum of squares	Mean square	F value
Entry	3	3,154.00	1,051.33	3.93*
Replication	4	1,267.50	316.88	1.19
Error	12	3,206.50	267.21	
Total	19	7,628.00		

*Significant

Table 20. Analysis of data in Table 17 designed to contrast K2234, US 35, and KIH 38 with K1585.

Source of variation	D/F	Sum of squares	Mean square	F value
K2234, KIH 38, and US 35	2	43.60	21.80	
K1585 vs. other three	1	3,110.40	3,110.40	11.64**
Error	12	3,206.50	267.21	

**Highly significant

single cross K41 x K55. The recessive susceptibility transmitted by Hy and L317 to their single crosses may have been responsible for the lack of correlation between actual and predicted results for US 35.

The results of a test to determine the relative resistance of "amargo" maize and the hybrids K1585, KIH 38 and US 35 are given in Table 22 and the analysis of variance in Table 23. A significant difference existed between entries, "amargo" having a mean reading of 46 percent damage and US 35 a mean reading of 83 percent damage. "Amargo", an Argentine maize secured from Jose M. Andres, University of Buenos Aires, is resistant to the attack of Schistocera paranensis and Dichroplus arrogans. The data indicate that "amargo" maize is also resistant to the attack of Melanoplus bivittatus, the grasshopper used in this study. The mean percent damage for entries would suggest that K1585 is somewhat more susceptible than "amargo." Statistically, however, the difference existing between "amargo" and K1585 could not be considered significant.

Table 21. Mean percent damage for the four non-parental single crosses of each of the four double crosses, K2234, K1585, US 35, and KIH 38.

K2234 (K41xK55)x(K63xK64)		K1585 (K155xK201)x(K4x38-11)		US 35 (L317x38-11)x(HyxR4)		KIH 38 (WF9x38-11)x(HyxR4)	
Single cross	Percent damage	Single cross	Percent damage	Single cross	Percent damage	Single cross	Percent damage
(K41 x K63)	51	(K155 x K4)	51	(L317 x Hy)	74	(WF9 x Hy)	81
(K41 x K64)	71	(K155 x 38-11)	45	(L317 x R4)	48	(WF9 x R4)	66
(K55 x K63)	68	(K201 x K4)	60	(38-11 x Hy)	40	(38-11 x Hy)	40
(K55 x K64)	51	(K201 x 38-11)	49	(38-11 x R4)	48	(38-11 x R4)	48
Mean	60.3	Mean	51.3	Mean	52.5	Mean	58.8

Fertility Levels and Grasshopper Resistance

Nitrogen Levels. Data obtained from the study of various nitrogen levels in 1942 are given in Table 24 and the analysis of variance in Table 25. This preliminary test indicated that nitrogen affected relative resistance. The 600 pound application of NH_4NO_3 (32.5 percent N) was most susceptible with a mean percent damage for all entries of 68 as compared to 42 percent damage for the check. The differences for entries were highly significant. K2234 had a mean percent damage reading of 66 as compared to 46 percent damage for DeKalb 816. These results are not in agreement with field observations, as K2234 was resistant and DeKalb 816 susceptible.

A highly significant F value for treatment by entry suggests that the hybrids differed in their ability to utilize nitrogen with a resultant difference in the ability of the hybrids to resist attack. It is to be noted that K2234 was more resistant than DeKalb 816 when the checks are compared; however, K2234 became much more susceptible with increased nitrogen whereas increased nitrogen did not affect the susceptibility of DeKalb 816. One would assume therefore that a differential ability of K2234 and DeKalb 816 to use available nitrogen brought about a discrepancy in the reaction of these lines. It has been shown by data presented in Tables 16 and 18 that when small numbers of plants were subjected to infestation K2234 acted in a susceptible manner. In the case of the data presented in Table 24 the nitrogen may have influenced DeKalb 816 to react in a resistant fashion to the extent where the grasshoppers were forced to feed on K2234. DeKalb 816 was not available for further tests in 1946.

The results of the nitrogen fertility level study conducted in 1946 are presented in Table 26, a summary of the data in Table 27, and the analysis of variance in Table 28. As shown by the analysis of variance the differences for treatments were highly significant. The corn plants treated with 600 pound applications of NH_4NO_3 (32.5 percent N) were most susceptible with a mean percent damage reading of 64 (Table 27) for all entries. The check and the 300 and 900 pound treatments were

Table 22. Estimated percentage damage of 3 double crosses and "amargo" maize tested in seedling stage at Manhattan, Kansas, 1946. Subjected to M. bivittatus.

Replication	"Amargo"	Kansas 1585	KIH 38	US 35	Mean
1	38	48	85	67	60
2	63	75	38	90	67
3	38	40	50	78	52
4	38	50	88	88	66
5	55	43	58	90	61
Mean	46	51	64	83	61

Table 23. Analysis of variance of data in Table 22.

Source of variation	D/F	Sum of squares	Mean square	F value
Entries	3	3,918.00	1,306.00	5.12*
Replication	4	592.00	148.00	
Error	12	3,068.00	255.67	
Total	19	7,578.00		

* Significant

Table 24. Differences in resistance to grasshoppers of 4 hybrids grown under various nitrogen levels, Manhattan, Kansas, 1942. Subjected to *M. bivittatus* and *M. differentialis.* (Tested in seedling stage.)

Treatment	Percent damage: Kansas 2234	Kansas 2182	US 35	DeKalb 816	Mean
A 1/	37	43	40	47	42
B	67	50	60	37	54
C	90	50	77	53	68
D	70	57	83	47	64
Mean	66	50	65	46	57

1/ A = Check B = 300# C = 600# D = 900#

Table 25. Analysis of variance of data in Table 24.

Source of variation	D/F	F value
Treatments	3	49.17*
Replications	2	9.15
Error (a)	6	3.45
Entries	3	12.61**
Treatment x entry	9	3.89**
Error (b)	24	

*Significant
**Highly significant

essentially alike in their reaction to grasshopper feeding. It is to be noted that a mean of 12 percent damage was obtained for K1585 (Table 26) for the 900 pound treatment. It is possible that the plants in this level escaped injury rather than actually having such a high degree of resistance. A highly significant difference is shown for entries (Table 28). The hybrids K2234 and K1585 were resistant and the hybrids US 35 and KIH 38 susceptible which is in accord with field observations.

Table 26. Differences in resistance to grasshoppers of 4 hybrids grown under various nitrogen levels, Manhattan, Kansas, 1946. Subjected to <u>M. bivittatus.</u> (Tested in seedling stage.)

Replication	Percent damage																Mean
	Kansas 2234				Kansas 1585				US 35				KIH 38				
	A 1/	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
1	25	43	43	20	70	30	67	13	37	43	53	90	47	15	87	10	44
2	17	27	27	13	23	50	63	10	90	57	43	40	47	70	70	37	43
3	50	17	67	13	20	43	63	10	67	47	85	25	50	57	70	90	48
4	27	20	60	63	13	40	63	15	63	50	85	90	80	87	67	87	57
Mean	30	27	49	27	32	41	64	12	64	59	67	61	56	57	74	56	48

1/ A = Check B = 300# C = 600# D = 900#

Table 27. Summary of data in Table 26.

Treatment	Percent damage: Kansas 2234	Kansas 1585	US 35	KIH 38	Mean
A 1/	30	32	64	56	46
B	27	41	50	57	44
C	49	64	67	74	64
D	27	12	61	56	39
Mean	33	37	61	61	48

1/ A = Check B = 300# C = 600# D = 900#

Table 28. Analysis of variance of data in Table 26.

Source of variation	D/F	Sum of squares	Mean square	F value
Treatments	3	5,410.29	1,803.43	4.33**
Replications	3	2,017.79	672.60	1.62
Entries	3	10,494.92	3,498.31	8.41**
Treatment x entry	9	3,071.27	341.25	
Error	45	18,725.96	416.13	
Total	63	39,720.23		

**Highly significant

Under greenhouse conditions adult grasshoppers of the two species used for this study chewed many of the plants off near the soil level making it difficult to evaluate properly damage (See Plate II, pots 3 and 4). In conjunction with the data presented in Table 26, a record was made of the number of plants chewed off. The percentage data of the number of plants chewed off as compared to the total number of plants for entry and fertility level is given in Table 29. In the case of both the entries and the nitrogen levels the mean percentage of plants chewed off seems to be in accord with the most susceptible entries and the most susceptible nitrogen level. Although no data other than the data in

Table 29. Total percentage of plants chewed off at ground level by grasshoppers. Hybrids grown under various nitrogen levels, Manhattan, Kansas, 1946. (Tested in seedling stage.)

Treatment	Percentage plants chewed off Kansas 2234	Kansas 1585	US 35	KIH 38	Mean
A 1/	0	17	25	25	17
B	0	17	0	27	11
C	17	25	20	67	32
D	0	0	20	20	10
Mean	4	15	16	35	18

1/ A = Check B = 300# C = 600# D = 900#

Table 29 were recorded, it was observed that the susceptible varieties in most cases had the larger number of plants chewed off at the soil surface. Nevertheless, feeding of this type may have made it impossible to measure small increases or decreases of resistance induced by the application of nitrogen and phosphorus fertility levels.

Phosphorus Levels. The results of the experiment in 1942 using various phosphorus levels are given in Table 30 and the analysis of variance in Table 31. No treatment differences were observed. A highly significant difference existed for entries, K2234 being most resistant and US 35 most susceptible. The entry means presented in Table 30 for K2234 and DeKalb 816 are in agreement with field results.

Table 30. Differences in resistance to grasshoppers of 4 hybrids grown under various phosphorus levels, Manhattan, Kansas, 1942. Subjected to M. bivittatus and M. differentialis. (Tested in seedling stage.)

Treatment	Percent damage				Mean
	Kansas 2234	Kansas 2182	US 35	DeKalb 816	
A 1/	53	60	80	83	69
B	47	63	90	83	71
C	43	63	87	77	68
D	37	63	83	87	65
Mean	45	60	83	82	68

1/ A = Check B = 225# C = 450# D = 675#

Table 31. Analysis of variance of data in Table 30.

Source of variation	D/F	F value
Treatments	3	0.74
Replications	2	.44
Error (a)	6	2.66
Entries	3	43.69**
Treatment x entry	9	.82
Error (b)	24	1.99

**Highly significant

The data for a second experiment designed to determine the effect of various phosphorus levels on resistance are presented in Table 32. An examination of the treatment means shows a consistently more resistant reaction for the B treatment for all entries as compared to the A, C and D treatments. The analysis of variance in Table 34 shows that the treatment differences were significant. An analysis of the treatment means in Table 33 shows that the B level was most resistant with 38 percent damage as compared to 60 percent damage for D, the most susceptible level. The A and C levels had somewhat the same reaction. A highly significant difference was obtained for entries, K2234 and K1585 being resistant, US 35 susceptible, and KIH 38 intermediate.

The analysis of variance of the data in Table 32 shows a highly significant difference for replications, suggesting that grasshoppers tended to congregate in this experiment. An examination of the mean percent damage for replications shows the difference is due to the percent damage existing in replication 4 as compared to replications 1, 2 and 3. Replications 1, 2 and 3 were relatively uniform. The grasshoppers had a tendency to mass and group on the end of the cage where replication 4 was located.

A third experiment was conducted using phosphorus levels to determine the validity of the data presented in Table 32. The data for this experiment are given in Table 35 and the analysis of variance in Table 37. The treatment differences were not significant. It is to be noted, however, that in the entries K1585, US 35 and KIH 38 the B treatment had the most resistant readings. In K2234 the B treatment gave the same results as C and D levels. The B treatment for K2234 had resistant readings (Table 35) for all replications except replication 2. The reason for the high reading obtained for the replication is not known. The 485 pound application of superphosphate (20 percent P_2O_5) may introduce a degree of resistance but it is likely this resistance can be measured only when feeding is relatively uniform and percent damage readings are taken before the grasshoppers are forced to feed on the more resistant plants.

Table 32. Differences in resistance to grasshoppers of 4 hybrids grown under various phosphorus levels, Manhattan, Kansas, 1946. Subjected to M. bivittatus. (Tested in seedling stage.)

Replication	Percent damage																Mean
	Kansas 2234				Kansas 1585				US 35				KIH 38				
	A 1/	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
1	25	30	17	40	57	15	10	30	90	65	47	90	57	27	30	87	45
2	40	23	37	50	33	23	50	25	57	50	87	77	37	60	25	37	44
3	47	20	27	63	60	15	37	33	80	37	63	90	43	23	90	60	49
4	43	17	55	57	33	33	90	90	83	80	77	77	77	85	90	53	65
Mean	39	23	34	53	46	22	47	45	78	58	69	84	54	49	59	59	51

1/ A = Check B = 485# C = 970# D = 1455#

Table 33. Summary of data in Table 32.

Treatment	Percent damage				Mean
	Kansas 2234	Kansas 1585	US 35	KIH 38	
A 1/	39	46	78	54	54
B	23	22	58	49	38
C	34	47	69	59	52
D	53	45	84	59	60
Mean	37	40	72	55	51

1/ A = Check B = 485# C = 970# D = 1455#

Table 34. Analysis of variance of data in Table 32.

Source of variation	D/F	Sum of squares	Mean square	F value
Treatments	3	4,260.88	1,420.29	4.14*
Replications	3	4,485.62	1,495.21	4.36**
Entries	3	12,469.63	4,156.54	12.12**
Treatment x entry	9	1,127.99	125.33	
Error	45	15,432.88	342.95	
Total	63	37,777.00		

* Significant
** Highly significant

In each of the three experiments conducted on the effect of various phosphorus levels on resistance, a highly significant difference was obtained for entries. An examination of the data presented in Tables 30, 33 and 36 shows that K2234, K1585 and K2182 reacted in a resistant manner and US 35, KIH 38 and DeKalb 816 reacted in a susceptible manner which is in agreement with field observations.

Table 35. Differences in resistance to grasshoppers of 4 hybrids grown under various phosphorus levels, Manhattan, Kansas, 1946. Subjected to M. bivittatus. (Tested in seedling stage.)

Repli-cation	Percent damage																Mean
	Kansas 2234				Kansas 1585				US 35				KIH 38				
	A 1/	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
1	20	17	27	30	47	20	33	43	47	43	50	87	83	80	67	30	45
2	23	83	60	47	17	17	30	20	60	87	50	53	37	60	70	43	47
3	27	17	27	40	30	17	50	27	63	47	50	87	83	47	63	87	48
4	23	30	17	33	23	20	37	40	73	20	90	67	67	20	80	43	43
Mean	23	37	35	38	29	19	38	33	61	49	60	74	68	52	70	51	46

1/ A = Check B = 485# C = 970# D = 1455#

Table 36. Summary of data in Table 35.

Treatment	Percent damage				Mean
	Kansas 2234	Kansas 1585	US 35	KIH 38	
A 1/	23	29	61	68	45
B	37	19	49	52	39
C	35	38	60	70	51
D	38	33	74	51	49
Mean	34	30	61	60	46

1/ A = Check B = 485# C = 970# D = 1455#

Table 37. Analysis of variance of data in Table 35.

Source of variation	D/F	Sum of squares	Mean square	F value
Treatments	3	1,236.25	412.08	1.24
Replications	3	292.13	97.38	
Entries	3	13,690.80	4,563.60	13.67**
Treatment x entry	9	2,497.95	277.55	
Error	45	15,013.87	333.64	
Total	63	32,731.00		

** Highly significant

Nitrogen and Phosphorus Levels. It would be expected that by designing an experiment using the phosphorus treatment which increased resistance as one level and the nitrogen treatment which decreased resistance as another level a marked differential in response by entries to grasshoppers could be obtained. The results from two experiments, one employing a 970 pound superphosphate and a 600 pound NH_4NO_3 treatment did not bear this out. It is to be remembered that the 485 pound treatment of superphosphate (20 percent P_2O_5) showed some ability to increase resistance. The data for the experiment that used a 970 pound

Table 38. Differences in resistant to grasshoppers of 4 hybrids grown under check, nitrogen, phosphorus and nitrogen plus phosphorus treatments, Manhattan, Kansas, 1946. Subject to <u>M. bivittatus.</u> (Tested in seedling stage.)

Replication	A 1/	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	Mean
1	80	13	60	87	77	50	57	60	67	83	53	90	80	70	90	87	69
2	40	80	57	27	57	37	33	40	77	90	73	80	40	70	60	77	59
3	63	53	23	43	13	40	40	43	70	77	70	77	77	73	90	90	59
4	40	33	77	63	77	43	73	83	67	33	67	87	17	53	43	63	57
Mean	56	45	54	55	56	43	51	57	70	71	66	84	54	67	71	79	61

A = Check B = 970# superphosphate C = 970# superphosphate plus 600# NH_4NO_3
D = 600# NH_4NO_3

superphosphate level are shown in Table 38 and the analysis of variance in Table 40. A summary of the data in Table 38 is given in Table 39.

Table 39. Summary of data in Table 38.

Treatment	Percent damage				
	Kansas 2234	Kansas 1585	US 35	KIH 38	Mean
A 1/	56	56	70	54	59
B	45	43	71	67	57
C	54	51	66	71	61
D	55	57	84	79	69
Mean	53	52	73	68	61

1/ A = Check B = 970# Superphosphate C = 970# superphosphate plus 600# NH_4NO_3 D = 600# NH_4NO_3

Table 40. Analysis of variance of data in Table 38.

Source of variation	D/F	Sum of squares	Mean squares	F value
Treatments	3	1,373.80	457.93	1.13
Replications	3	1,389.55	463.18	1.15
Entries	3	5,451.18	1,817.06	4.49**
Treatment x entry	9	1,534.26	170.47	
Error	45	18,198.20	404.40	
Total	63	27,946.99		

**Highly significant

The analysis of variance (Table 40) indicated that the differences existing between treatments were not significant. Entry differences, which were highly significant statistically, are in agreement with differences for entries presented for previous tests.

Table 41. Differences in resistance to grasshoppers of 4 hybrids grown under check, nitrogen, phosphorus, and nitrogen plus phosphorus treatments, Manhattan, Kansas, 1946. Subjected to *M. bivittatus.* (Tested in seedling stage.)

Replication	Percent damage																Mean
	Kansas 2234				Kansas 1585				US 35				KIH 38				
	A 1/	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
1	43	17	47	43	20	17	47	17	63	47	57	47	40	50	30	70	41
2	23	43	43	27	27	37	17	47	53	57	83	83	37	50	37	50	45
3	80	27	57	30	63	30	40	40	53	30	87	70	80	57	87	83	57
4	17	67	60	43	43	43	90	80	60	83	67	73	83	90	53	67	64
Mean	41	39	52	36	38	32	49	46	57	54	74	68	60	62	57	68	52

1/ A = Check B = 485# superphosphate C = 485# superphosphate plus 600# NH_4NO_3 D = 600# NH_4NO_3.

Table 42. Summary of data in Table 41.

Treatment	Percent damage				Mean
	Kansas 2234	Kansas 1585	US 35	KIH 38	
A 1/	41	38	57	60	49
B	39	32	54	62	47
C	52	49	74	52	56
D	36	46	68	68	54
Mean	42	41	63	61	52

1/ A = Check B = 485# superphosphate C = 485# superphosphate plus 600# NH_4NO_3 D = 600# NH_4NO_3

Table 43. Analysis of variance of data in Table 41.

Source of variation	D/F	Sum of squares	Mean square	F value
Treatment	3	997.07	332.36	1.12
Replications	3	5,423.57	1,807.86	6.07**
Entries	3	6,719.74	2,239.91	7.52**
Treatment x entry	9	1,787.13	198.57	
Error	45	13,405.93	297.91	
Total	63	28,333.44		

**Highly significant

Data obtained for the experiment using a 485 pound treatment of superphosphate are given in Table 41, a summary of the data in Table 42 and the analysis of variance in Table 43. Treatment differences were not significant. A highly significant difference existed for replications, suggesting the grasshoppers tended to mass in this experiment. An examination of the mean percent damage for replications in Table 41 shows a gradual increase from replication 1 to replication 4. The lack of uniformity in feeding by grasshoppers in this experiment may have been caused primarily by the influence of a temperature gradient. Replication 1 appeared on the south end of the cage and on extremely hot days it is possible that the north end of the cage was somewhat cooler, causing the grasshoppers to mass on replications 3 and 4.

The data in Tables 24 through 43 indicate variable results for fertilizer treatments and strikingly similar results for entries. It is doubtful that nitrogen and phosphorus levels had much influence in this experiment in increasing or decreasing resistance of either the resistant or susceptible hybrids. One should note, however, that the application of 600 pounds of ammonium nitrate (32.5 percent) decreased the resistance of the resistant and susceptible hybrids in most cases and that the application of 485 pounds of superphosphate (20 percent P_2O_5) had a tendency to increase resistance.

DISCUSSION

Sporadic outbreaks of grasshoppers represent one of the greatest insect hazards in corn production in the Great Plains area. Few records are available that give estimates of the percent of corn crops destroyed by grasshoppers during years of severe infestations. Parker (42) reported that a careful record of grasshopper damage was kept in North Dakota during the grasshopper outbreak of 1933. The loss to the corn crop in that state was 16 percent. Although few, if any, actual estimates of the monetary value of the corn crop destroyed by grasshoppers exist, the above record of the total crop destroyed in one state serves as an indication of the seriousness of the grasshopper problem during years of abundance.

The development and use of resistant strains of corn could well become an important means of controlling grasshopper damage. Available literature suggests that the use of both chemical control and host resistance may prove much more effective than either means of control used alone. Sanderson (46) has reported that in Arkansas the cotton plant exerted a depressing force on populations of *Melanoplus differentialis* and *M. bivittatus*, the two species that do more damage to corn than any other species. If cotton is unsatisfactory for maintaining growth and fecundity, is it not possible that resistant strains of corn would react in a similar fashion?

Previous records, observations and the results of this study definitely demonstrate the differential ability of open pollinated varieties, inbreds, and hybrids to resist attack.

One should remember, however, that grasshopper resistance in corn is relative and under extreme infestations all corn varieties and hybrids thus far studied can be destroyed. The hybrid K1585 displayed a high type of resistance in the field and in all tests conducted in the greenhouse. All differences observed in this study between two resistant and two susceptible hybrids were highly significant. Such differences in many cases may mean the difference between crop failure and a good yield.

One would expect the open pollinated varieties of corn exposed for the longest time to the attacks of grasshoppers to be the most resistant and that natural selection would be a determining factor in separating out resistant genes. Evidence in support of this assumption is available. Brunson and Painter (8) stated that natural selection operating in the development of adapted varieties of corn has operated to eliminate the variants most susceptible to grasshopper injury. The recorded observations for 1941 show that ten inbred lines selected from Pride of Saline in all cases transmitted a fairly high degree of resistance to the single cross combinations among them. It is evident that natural selection intensified resistance to grasshoppers in the variety Pride of Saline, and that this resistance was retained in the inbred lines selected from it.

The reason for the so-called grasshopper resistant strains of corn being more resistant to attack than grasshopper susceptible strains is not known. Horovitz and Marchioni (27) reported that hairiness of leaf and the pigments, anthocyanin and flavones, were not associated with susceptibility or resistance. Two other factors as possible explanations for differences in resistance were considered by Brunson and Painter (8) during the outbreak of grasshoppers in Kansas in 1936. They suggested that the gregarious habit of the grasshoppers and time of flowering of strains planted at the same time had no relation to differences in injury to individual plants and strains of corn. Studies made in 1941 indicate that for 89 varieties and hybrids observed, highly significant negative correlations existed between the two variates ear height and pollen shedding and the variate percent injury. It is doubtful this relationship had any true value. For the most part the later maturing strains were composed of inbreds selected from Kansas open pollinated varieties having a high degree of resistance and the susceptible strains originated in out of state areas where an earlier maturing hybrid is needed and grasshopper outbreaks are seldom experienced.

A possible explanation for the differential injury recorded in the greenhouse may be based on height of seedling plants. One might readily believe that the grasshoppers would roost on the taller plants and consequently the greater amount of feeding would take place on these plants. A scatter diagram of the mean height of plants and the mean percent damage for both inbreds and single crosses showed no consistent relationship between injury and height of plants.

The feeding of grasshoppers on corn under field conditions in all cases observed consisted mainly of the destruction of the tender portions of the leaf blade, leaving the bare midrib. In the controlled infestations of adult grasshoppers on seedling corn plants, the plants were frequently chewed off at or near the soil surface. Further studies with seedling corn plants should be confined to controlled infestations by grasshoppers in their second to fourth instar stage of development. The results for this study indicated comparable results for grasshoppers regardless of stage of growth. However, when plants are chewed off at the soil surface it is doubtful that an estimation of injury sustained can be a true estimation in all cases. It was noted that the nymphs confined themselves almost entirely to leaf feeding.

As was shown by the statistical analysis for the greenhouse data, significant differences between replications existed in some instances. The two factors, light and temperature, appeared to play a decided role in causing a discrepancy in the amount of feeding from one replication to the next. The nymphs used in this study tended to place themselves on the side of the cage most nearly in direct sunlight. In the case of the adult grasshoppers, temperature suggested itself as a very important factor affecting feeding. High temperature caused an increase in amount of food taken in the somewhat more shaded portions of the cage as well as a larger number of plants being chewed off at the soil surface. This latter condition may well have been associated with a water requirement, the conducting tissue of the stem fulfilling such a need.

The close agreement obtained between the grasshopper reaction of inbred lines and hybrids under greenhouse and field conditions demonstrates the feasibility and value of controlled infestation as an aid in breeding for grasshopper resistance in corn. To realize the greatest benefit from the available knowledge regarding grasshopper resistance in corn, the greenhouse method of controlled infestation used in this study should lend itself readily for studies on the mode of inheritance of resistance of corn strains to grasshopper attack. Fundamental information from such studies should lead to a scientific appreciation of the problem and to a sound basis for solution.

SUMMARY AND CONCLUSIONS

The differential feeding of grasshoppers on strains of corn was studied under field conditions in 1941 and under greenhouse conditions in 1942 and 1946. The study resolved itself into two phases; first, the inherent resistance of inbred lines of corn to attack and the transmittal of this resistance to hybrids; second, the effect of nitrogen and phosphorus fertility levels in increasing or decreasing the resistance of susceptible and resistant hybrids.

The infestation of grasshoppers in the corn test plots on the Agronomy Farm in 1941 resulted in outstanding instances of differential injury among corn varieties and hybrids. In one planting of 89 varieties and commercial and promising hybrids, percentage of leaf surface removed ranged from 10 to nearly 100 percent. The extreme range of defoliation for the single crosses observed varied from 10 to 60 percent.

In one experiment on the Agronomy Farm involving single cross combinations among 10 midseason yellow inbred lines, the inbreds Oh 07 and US 540 transmitted the most resistant reaction and their mean percent damage readings were essentially the same. Oh 07 is a selection out of the cross US 540 x Ill L. Apparently the resistant reaction carried by US 540 was transmitted to the selection of Oh 07.

Under field conditions the resistance transmitted by US 540, Oh 07, and Ky 27 tended to be dominant and the susceptibility transmitted by Hy and 33-16 recessive.

The transmission of grasshopper reaction by 41 inbreds to single cross combinations tested on the Agronomy Farm in 1941 indicates that hereditary differences in resistance to grasshoppers existed among these inbred lines.

Greenhouse studies indicate that susceptibility of resistance can be transferred to a hybrid by the backcross method of breeding.

When the two inbred lines K41 and K55, both intermediate in their reaction to grasshoppers, were combined and tested under greenhouse conditions a resistant single cross resulted. The response of K41 x K55 can perhaps best be explained on the assumption of complementary factors contributed by the two parents.

The data obtained for twelve inbred lines under greenhouse conditions indicate marked differences occurred among these inbreds in the transmission of resistance or susceptibility to their hybrids. Single crosses involving R4 and 38-11 tended to be resistant, except for combination with WF9. The crosses involving WF9 were uniformly susceptible. The data suggest that the susceptibility carried by WF9 was dominant, whereas susceptibility derived from L317 and Hy tended to be recessive. The combination of the susceptible inbred line Hy with the inbreds WF9 and L317 produced a cumulative effect for susceptibility in both cases.

A comparison of the relative resistance of the inbred lines, when used in hybrid combination with the percent damage to the individual inbred tested under artificial conditions, indicates, without question, that resistance is inherited.

A comparison of the reaction of twelve inbred lines when tested as individual inbreds and in single cross combination in the greenhouse and when tested in single and top cross combination under field conditions, shows a very close agreement between these two sets of conditions.

"Amargo" maize, an Argentine variety resistant to the attack of Schistocera paranensis and Dichroplus arrogans, was found to be resistant to Melanoplus bivittatus but not much more resistant than the resistant Kansas hybrid, K1585.

The data obtained for this study for nitrogen and phosphorus fertility level treatments are variable. It is doubtful that nitrogen and phosphorus levels had much influence in these tests in increasing or decreasing resistance of either the resistant or susceptible hybrid. In two cases the application of 600 pounds of NH_4NO_3 (32.5 percent N) decreased the resistance of the resistant and susceptible hybrids. The application of 485 pounds of treble superphosphate (20 percent P_2O_5) increased resistance in one experiment.

A striking similarity was obtained in nearly all cases between the reaction of the two susceptible hybrids, US 35 and KIH 38, and the two resistant hybrids, K1585 and K2234, in the tests conducted under greenhouse conditions as compared to the reaction of these four hybrids when observed under field conditions.

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LITERATURE CITED

(1) Allen, M. W., and R. H. Painter.
Observations on the biology of the wheat stem maggot in Kansas. Jour. Agr. Res. 55:215-238. 1937.

(2) Bigger, J. H.
Resistance of certain wheat varieties to attack by the wheat stem maggot, Meromyza americana (Fitch). Jour. Amer. Soc. Agron. 30:448. 1938.

(3) ____________.
Insect resistance in corn. Jour. Amer. Soc. Agron. 35:689-695. 1943.

(4) ____________, J. R. Holbert, W. P. Flint, and A. L. Lang.
Resistance of certain corn hybrids to attack of southern corn footworm. Jour. Econ. Ent. 31:102-107. 1938.

(5) ____________, R. O. Snelling, and R. A. Blanchard.
Resistance of corn strains to the southern corn rootworm, Diabrotica duodecimpunctata (F.). Jour. Econ. Ent. 34:605-613. 1941.

(6) Blanchard, R. A., J. H. Bigger, and R. O. Snelling.
Resistance of corn strains to the corn ear worm, Heliothis armigera (Hb.). Jour. Amer. Soc. Agron. 33:344-350. 1941.

(7) ________________, and J. E. Dudley, Jr.
Alfalfa plants resistant to the pea aphid. Jour. Econ. Ent. 27:262-264. 1934.

(8) Brunson, A. M., and R. H. Painter.
Differential feeding of grasshoppers on corn and sorghums. Jour. Amer. Soc. Agron. 30:334-346. 1938.

(9) Caldwell, R. M., W. B. Cartwright, and L. E. Compton.
Inheritance of Hessian fly resistance derived from W38 and Durum P. I. 94587. Jour. Amer. Soc. Agron. 38:398-409. 1946.

(10) Cartwright, W. B., and G. A. Wiebe.
Inheritance of resistance to the Hessian fly in the wheat crosses Dawson x Poso and Dawson x Big Club. Jour. Agr. Res. 52:691-695. 1936.

(11) Clark, J. A.
Improvement in wheat. U.S.D.A. Yearbook, 1936:207-302. 1936.

(12) Dahms, R. G., and F. A. Fenton.
The effect of fertilizers on chinch bug resistance in sorghums. Jour. Econ. Ent. 33:688-692. 1940.

(13) Dahms, R. G., and J. H. Martin.
Resistance of F_1 sorghum hybrids to the chinch bug. Jour. Amer. Soc. Agron. 32:141-147. 1940.

(14) ____________, and R. H. Painter.
Rate of reproduction of the pea aphid on different alfalfa plants. Jour. Econ. Ent. 33:482-485. 1940.

(15) ____________, R. O. Snelling, and F. A. Fenton.
Effect of different varieties of sorghum on biology of the chinch bug. Jour. Amer. Soc. Agron. 28:160-161. 1936.

(16) Dodd, A. P.
The control and eradication of prickly pear in Australia. Bul. Ent. Res. 27:503-522. 1936.

(17) Dunham, R. S.
Stem maggot injury among wheat varieties. Jour. Amer. Soc. Agron. 26:978-980. 1934.

(18) Evans, A. C.
Physiological relationships between insects and their host plants. I. The effect of the chemical composition of the plant on reproduction of winged forms in Brevicoryne brassicae (L.). Ann. Appl. Biol. 25:558-572. 1938.

(19) Flint, W. P.
Chinch bug resistance shown by certain varieties of corn. Jour. Econ. Ent. 14:83-85. 1921.

(20) Foster, W. R., and C. E. Jeffery.
Resistance of winter wheat to Hessian fly. Canad. Jour. Res. 15:135-140. 1937.

(21) Haseman, L.
Influence of soil minerals on insects. Jour. Econ. Ent. 39:8-11. 1946.

(22) Havens, J. N.
Observations on the Hessian fly. Soc. Agr. New York Trans., Pt. 1:89-107. 1792.

(23) Hayes, W. P., and C. O. Johnston.
The reaction of certain grasses to chinch bug attack. Jour. Agr. Res. 31:575-583. 1925.

(24) Hehn, E. R.
Studies on the resistance of spring wheat varieties to grasshopper, Melanoplus bivittatus (Say), attack. Thesis submitted for the degree Master of Science, South Dakota State College. 1942.

(25) Hermann, W., and R. Eslick.
Susceptibility of seedling grasses to damage by grasshoppers. Jour. Amer. Soc. Agron. 31:333-337. 1939.

(26) Holbert, J. R., W. P. Flint, and J. H. Bigger.
Chinch bug resistance in corn an inherited character. Jour. Econ. Ent. 27:131-124. 1934.

(27) Horovitz, S., and A. H. Marchioni.
Inheritance of the resistance to the locust in "amargo" maize. Anales del Instituto Fitotecnico de Santa Catalina. 2:27-52. 1940. (Published 1942)

(28) Huber, L. L., and G. H. Stringfield.
Aphid infestation of strains of corn as an index of their susceptibility to corn borer attack. Jour. Agr. Res. 64:283-291. 1942.

(29) Hume, A. N.
An indication of the relative susceptibility of dent and flint corn to injury by grasshoppers. Jour. Amer. Soc. Agron. 23:1071. 1931.

(30) Isely, F. B.
Correlation between mandibular morphology and food specificity in grasshoppers. Ann. Ent. Soc. Am. 37:47-67. 1944.

(31) Jacobson, L. A., and C. W. Farstad.
Some observations on differentials feeding on maturing wheat varieties by grasshoppers. Canad. Ent. 73:158-159. 1941.

(32) Jones, E. T.
Differential resistance to chinch bug attack in certain strains of wheat. Trans. Kan. Acad. Sci. 40:135-142. 1937.

(33) ___________.
Grasses of the tribe Hordeae as hosts of the Hessian fly. Jour. Econ. Ent. 32:505-510. 1939.

(34) Mangelsdorf, P. C., and R. C. Reeves.
The origin of Indian corn and its relatives. Texas Agr. Exp. Sta. Bul. 574. 1939.

(35) Marston, A. R.
Breeding European corn borer resistant corn. Jour. Amer. Soc. Agron. 23:960-964. 1931.

(36) Mathur, R. N.
Certain observations on the nitrogen nutrition of the sugar-cane plant in relation to susceptibility to attack of white-fly. Proc. 10th Conv. Sug. Tech. Assoc. India pp. 45-53. 1941.

(37) Noble, W. B., and C. A. Suneson.
Differentiation of the two genetic factors for resistance to the Hessian fly in Dawson wheat. Jour. Agr. Res. 67:27-32. 1943.

(38) Painter, R. H.
The economic value and biologic significance of insect resistance in plants. Jour. Econ. Ent. 34:358-367. 1941.

(39) ____________, and A. M. Brunson.
Differential injury within varieties, inbred lines, and hybrids of field corn caused by the corn earworm, Heliothis armigera (Hbn.). Jour. Agr. Res. 60:81-100. 1940.

(40) ____________, E. T. Jones, C. O. Johnston, and J. H. Parker.
Transference of Hessian fly resistance and other characteristics of Marquillo spring wheat to winter wheat. Kan. Agr. Exp. Sta. Tech. Bul. 49. 1940.

(41) ____________, R. O. Snelling, and A. M. Brunson.
Hybrid vigor and other factors in relation to chinch bug resistance in corn. Jour. Econ. Ent. 28:1025-1030. 1935.

(42) Parker, J. R.
1. The grasshopper problem in the United States. 2. Summary of losses and expenditure due to grasshoppers in the United States during the period 1925-1934. Fourth International Conference for Anti-Locust Research. 1936.

(43) Patch, L. H., J. R. Holbert, and R. T. Everly.
Strains of field corn resistant to the survival of the European corn borer. U.S.D.A. Tech. Bul. 823. 1942.

(44) Reitz, L. P., E. T. Jones, C. O. Johnston, and R. H. Painter.
Agronomic tests of new resistant varieties and hybrids of hard red winter wheat in the presence of stem rust and Hessian fly. Jour. Amer. Soc. Agron. 35:216-229. 1943.

(45) Riley, C. V.
First annual report, U. S. Entomological Commission for 1877. Washington Govt. Printing Office. 1878.

(46) Sanderson, M. W.
Crop replacement in relation to grasshopper abundance. Tabs. Jour. Econ. Ent. 32:484-486. 1939.

(47) Shotwell, R. L.
Species and distribution of grasshoppers responsible for recent outbreaks. Jour. Econ. Ent. 31:602-610. 1938.

(48) Smith, R. W.
Grasshopper injury in relation to stem rust in spring wheat varieties. Jour. Amer. Soc. Agron. 31:818-821. 1939.

(49) Snedecor, G. W.
Statistical Methods. Collegiate Press Inc., Ames, Iowa. 1946.

(50) Snelling, R. O.
Resistance of plants to insect attack. Bot. Rev. 7:543-586. 1941.

(51) ______________, R. A. Blanchard, and J. H. Bigger.
Resistance of corn strains to the leaf aphid, Aphis maidis (Fitch). Jour. Amer. Soc. Agron. 32:371-381. 1940.

(52) ______________, R. H. Painter, J. H. Parker, and W. M. Osborn.
Resistance of sorghums to the chinch bug. U. S. Dept. Agr. Tech. Bul. 585. 1937.

(53) Swenson, S. P.
Differential injury by grasshoppers on varieties of wheat, barley, and oats. Unpublished paper presented at a meeting of the Amer. Soc. Agron. in Chicago. 1940.

(54) Swingle, M. C.
The effect of previous diet on the toxic action of lead arsenate to leaf-feeding insects. Jour. Econ. Ent. 32:884. 1939.

(55) Wilbur, D. A., R. F. Fritz, and R. H. Painter.
Grasshopper problems associated with strip cropping in Western Kansas. Jour. Amer. Soc. Agron. 34:16-30. 1942.