# THE EPIDEMIOLOGY OF WHEAT STREAK MOSAIC VIRUS

by

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## INTRODUCTION

Wheat streak mosaic virus was first reported in 1922 in Nebraska (41). The first report of the disease in Kansas came in 1929 (29). The disease was considered of minor importance until the severe epidemic of 1949 when the disease loss was estimated to be $30,000,000 (15).

The disease is widespread throughout western United States and Canada. It has been reported to occur in Kansas (29), California (19), South Dakota (38), Arizona, Colorado, and Oklahoma (24), Washington (27), Montana (1), Wyoming (42), Nebraska (41), and in Alberta, Canada (39).

In 1953 Slykhuis (39) discovered that the eriophid mite, _Aceria tulipae_ (Keifer), was the vector of the disease. This was later confirmed by others (7, 8, 41). The mite, _A. tulipae_, was found by this discovery to be an important link in the epidemiology of wheat streak mosaic virus.

Many intensive studies (3, 4, 5, 6, 13, 23, 31, 33, 34, 36, 37, 39) have been completed to determine the host range of the virus. These studies have covered a wide range of monocetyledonous as well as several dicetyledonous families of plants. Most of the search has centered on members of the Gramineae in which many species of native grasses were found to be susceptible or symptomless carriers of the virus. Most of the species tested, however, are apparently immune to the disease.

Because of the extensive host range of the virus in the

Graminae and the severity of the disease, many teams of plant pathelogists have engaged in an effort to discover more concerning the nature of the virus and to devise means for its control.

## METHODS OF PREDICTING AN EPIDEMIC

A method of predicting the incidence of wheat streak mosaic virus was reported by Fellows and Sill (11) in 1955. In this method samples of wheat plants were collected at approximately 10 mile intervals in the areas surveyed. Each sample consisted of 12 to 20 plants picked at random from 4 different areas of a field. These samples were placed in the greenhouse and observed periodically for the development of symptoms. From the resulting percentage of infected plants it was possible to determine the location, the relative abundance and the approximate severity of the developing epidemics.

The loss predictions were determined to be valid for the following reasons:

1. The virus must be very widespread and abundant to do great damage. Hence, small samples are sufficient to indicate the major epiphytotic trends.
2. Wheat plants must be infected in the fall when plants are young if yield reductions are to be severe.
3. Spring infections of winter wheat have caused only slight losses, sometimes none, even in susceptible varieties. Consequently, these may be ignored safely in the survey and still achieve satisfactory results.

This method of prediction proved to be accurate over a period of 5 years and enabled Fellows and Sill to accurately divide the $14,000,000 loss of 1954 into 5 general areas depending upon the disease severity within each area. This method, although accurate, has proven to be time consuming and costly.

Since Slykhuis' discovery that the Eriophyid mite, A. tulipae, was the vector of the disease, another prediction method has been utilized. This is being carried on as a cooperative venture of the U.S.D.A., A.R.S., Entomology Research Service, the Field Crop Research Service of the U.S.D.A. and the Entomology and Botany and Plant Pathology Departments of Kansas State University. The nature of this project requires the services of many workers at a given time to make a quick but thorough survey of the state. It has been the author's privilege to participate in these surveys for the past 2 years. The work is coordinated by Mr. H. W. Semsen, U.S.D.A. Entomologist, stationed at Kansas State University.

The method is valid for the reasons given for the diseased plant prediction method. It involves making stops approximately every 10 miles along the highways of the state. Samples are taken of the wheat plants and examined under the binocular microscope in the car for the presence or absence of mites. This is a superficial examination and if the mites are not abundant and readily apparent, the samples are wrapped in aluminum foil and placed in an ice chest. These samples are brought back to Kansas State University where they are given a more detailed examination. By this means the presence or absence of mites can be plotted on maps indicating the location and relative abundance of mite populations. This method, however, does not indicate the percentage of mites which are viruliferous.

Since 1954, spring and fall surveys have been made throughout the state of Kansas. The results of these surveys are given in Table 1 of the Appendix. These results show high mite populations when disease incidence is high and low mite populations when the disease incidence is low thus assuring the probable validity of the method for disease prediction.

## VIRUS HOST RANGE IN RELATION TO EPIDEMIOLOGY

### Review of Literature

McKinney (25) tested wheat, bromegrass, Golden Giant sweet corn, and sugar cane (selfed hybrid Otabeite x C.P. 1161). The results indicated apparent immunity to wheat streak mosaic virus in bromegrass, chlorotic local lesions in sugar cane, systemic infection in wheat and yellow spots and/or small rings in sweet corn. In 1949 (23) he tested 39 representatives of wheat and wheat relatives as well as 5 varieties of winter barley, 24 varieties of oats and 21 varieties of field and sweet corn. His results are included in Table 2 of the Appendix.

In 1951 McKinney and Fellows (26) tested 88 species of native and forage grasses. Their results are included in Tables 3 and 4 of the Appendix. Slykhuis (37) in 1951 tested the following grasses as possible hosts of the wheat streak mosaic virus: Setaria glauca[1] S. viridis (L.) Beauv., Echinochlea crusgalli (L.) Beauv. and Panicum capillare L. He concluded that S. viridis was susceptible to the virus and served as a means of perpetuating the virus from harvest until the emergence of volunteer wheat.

In 1953 Sill and Connin (34) summarized the then known hostrange of the virus. These known hosts are given in Tables 2 through 6 of the Appendix.

Bellingham (3) in 1954 tested Beuteloua gracilis (H.B.K.), B. curtipendula (Michx.) and Buchloe dactyloides (Nutt.). His results indicated apparent immunity of the grasses to the virus.

In 1955 Sill and Agusiobe (33) tested a wide variety of crop plants, grasses, other monocetyledonous plants and a few dicetyledonous plants as possible hosts of the wheat streak mosaic virus. Their results are summarized in Tables 7through 11 of the Appendix. Slykhuis (36) also tested some of the wild grasses and used not only a manual method of inoculation but also tested them with viruliferous mites. His results are given in Table 12 of the Appendix.

Connin (5) tested many species of native grasses as possible hosts for both the virus and the mite vector. His results are given in Table 13 of the Appendix.

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[1]Probably should be Setaria lutescens (Weigel) Hubb. See pp. 718-719, Hitchcock, A.S. Manual of the Grasses of the United States, 2nd Edition revised by Agnes Chase, U.S.D.A. Misc. Pub. No. 200, Washington, D.C.: 1956.

Slykhuis (36) reported that the relative importance of the native grasses in Canada had not been determined. Staples and Allington (41) attempted to determine the relative importance of both the annual and perennial grasses in the epidemiological development of wheat streak mosaic virus. In their discussion they came to the conclusion that the native grasses were "relatively unimportant". Sill and Connin (34) said, "The host range of an economically important plant virus is of considerable significance since alternate hosts often serve as virus reservoirs".

## Materials and Methods

Greenhouse Facilities. In the author's experiment all plants were grown in the southwest section of the mosaic greenhouse at Kansas State University.

The seeds were planted in 5 or 6 inch pots in a soil that was mixed with sand, vermiculite and sheep manure to obtain a soil favorable for good plant growth.

The daily temperature of the greenhouse varied somewhat during the spring and fall but averaged approximately 70°F. during the winter. No plants were grown in the greenhouse from the middle of July until the middle of September, thus the test plants were not subjected to prolonged periods of high temperatures. On days when the temperature approached 100°F. in the greenhouse, the gravel floor was soaked with water twice daily to maintain a high humidity and to cool the house somewhat by the process of evaporation.

Routine greenhouse procedures. A number of routine greenhouse procedures were followed. These included the use of Kapco water soluble fertilizer (15-30-15) applied approximately once monthly according to the manufacturer's recommendations. Weekly or twice weekly fumigations were carried out throughout the length of the experiments using Plantfume 103 (a smoke generator active ingredient tetraethyl dithiopyrophosphate, 15 percent) to control or prevent any mite population buildup.

To minimize attacks of damping off fungi against seedling grasses, a routine procedure was followed in using Pano-drench 4 (active ingredient, 0.6 percent Cyano (methylmercuri) guanidine) diluted according to the manufacturer's recommendations.

All glassware or porcelain used in the experiments was sterilized prior to use for a minimum of 20 minutes in an Arnold sterilizer. This procedure was followed to inactivate any virus remaining on the utensils from previous usage.

Hands and forearms were thoroughly washed with soap and water before and after every inoculation. Following washing, the hands were rinsed in 95 percent ethyl alcohol and the alcohol was then removed by prolonged rinsing to remove the possibility of the alcohol accidentally injuring the plants tested.

Healthy control plants of each species tested were maintained at all times to check for accidental contamination. Whenever inoculations were made on native grasses, Pawnee wheat was also inoculated to assure the infectivity of the virus inoculum and to make certain the inoculation technic resulted in only minimum plant injury. At no time did healthy control plants show symptoms.

Virus Strain Used and Inoculum Preparation. The most common strain of the wheat streak mosaic virus found in Kansas, the Salina strain, *Marmer virgatum* var. *typicum* McK. strain I (22) or strain A (21), was utilized in all inoculations.

The inoculum was prepared by grinding leaf blades of the virus source plants to a pulp in a mortar and pestle. The ratio of 1 gm. of leaf tissue to 10 mls. of tap water was used. To facilitate the grinding of the narrow leaf blades, sterilized white sand was added to the leafy material. The dry pulp remaining after a thorough grinding was discarded. Carborundum (400-600 mesh) was added to the resulting liquid as an abrasive to aid in obtaining infection.

Seed Sources. Seeds of the native grasses were obtained from a wide variety of sources. Many were collected on survey trips to various areas of the state. Other seeds were obtained from Dr. Lloyd Hulbert, Assistant Professor of Botany, Kansas State University, Manhattan, Kansas. Dr. Hulbert also identified many plants that were collected in the field.

Other seeds were received from the following sources: Dr. William R. Kneebone, U.S.D.A., Agricultural Research Service, Woodward, Oklahoma; Dr. Max Hoover, U.S.D.A., Regional Plant Introduction Station, Ames, Iowa; Dr. A. A. Beetle, University

of Wyoming, Laramie, Wyoming; Dr. Herbert Schaaf, U.S.D.A., Agricultural Research Service, Mandan, North Dakota; Dr. Robert Olsen, U.S.D.A., Soil Conservation Service, Pullman, Washington; Dr. Lowell Mullen, U.S.D.A., Regional Plant Introduction Station, Pullman, Washington; and Dr. Jack R. Harlan, Oklahoma State University, Stillwater, Oklahoma.

A deep indebtedness is owed to the above men who so willingly and readily sent seeds for testing.

Inoculation Procedure. The method adopted was that of manual or abrasive sap inoculation. The sap was prepared in the manner previously described. The fingers were dipped into the sap-carborundum mixture and placed at the crown of the plant to be inoculated. The fingers were then stroked upwards 5 times with "enough pressure to make the leaves sing". This pressure was considered enough to injure the leaves slightly thus allowing a means of entrance for the virus with a minimum of leaf damage.

Grasses were grown and when they reached a stage of growth where inoculation could be accomplished with a minimum of damage, they were inoculated by the procedure mentioned above. A minimum of 50 plants of each species tested were inoculated in each of 2 separate trials. One month after inoculation of the native grasses, an attempt was made to recover the virus from each. This was done by preparing inoculum from each inoculated native grass by the procedure mentioned above. The sap was inoculated into healthy Pawnee wheat plants at the 3 to 4 leaf stage. This procedure, of attempting to recover the virus from all plants, enabled the discovery of any plants which were infected and yet failed to express symptoms.

After a second month had passed another attempt was made to recover the virus from the native grasses. This second recovery attempt was made in case the virus had a longer than normal incubation period in any of these grasses and also to determine if the plants which were infected the first month were still infected after 2 months.

Natural Infection. Occasionally plants were found in or near infected fields which showed apparent symptoms of a virus. These plants were collected, wrapped in aluminum foil and placed in a portable ice chest. They were transported to the greenhouse where they were identified and an attempt was made to recover the virus. The sap preparation was inoculated into Pawnee wheat plants in the 3 to 4 leaf stage. After inoculation the plants were examined periodically for symptoms.

## Experimental Results

Many of the native grasses tested by the artificial inoculation method proved to be apparently immune to the virus. These data are summarized in Table 14 of the Appendix.

Two new symptomless carriers of the virus were found. They are *Sporobolus airoides* (Torr.) and *S. cryptandrus* (Terr.). A total of 4 seed sources was tested for each species and all seed sources gave the same reaction. These grasses are listed in

Table 15 of the Appendix.

Two susceptible grasses were also found. They are Sitanion hystrix (Nutt) and Sporobelus neglectus Nash. Sitanion hystrix has been reported by Sill (34) as occurring naturally infected in the field but it has not previously been tested in the greenhouse for susceptibility. These grasses are listed in Table 16 of the Appendix.

Many grasses were found, occurring in or near infected wheat fields, that were suspected of being naturally infected. The wheat streak mosiac virus was recovered from the following grasses: Aegilops cylindrica Host. (Jointed Goatgrass), Avena sativa var. Mo. -205 L. (Cultivated oats), Bromus tectorum L. (Downy Chess), Panicum capillare L. (Ticklegrass) and Setaria viridis (L.) (Green Foxtail).

## Discussion

The inoculation results obtained are comparable to those obtained by others (3, 5, 36, 41). Bellingham (3) also reported Bouteloua gracilis, B. curtipendula and Buchloe dactyloides as immune to the virus. This has been confirmed during these studies in which a probable wider genetic range of seed sources was tested. The results also confirm the report by Slykhuis (36) as to the apparent immunity of Hordeum jubatum L. As Setaria lutescens is one of the common roadside grasses in wheat growing areas, it has been studied by several (36, 41) workers. Their results as to the apparent immunity of this grass was confirmed during these experiments.

*Setaria viridis*, collected at 2 different locations, was found to be naturally infected in the field. Others (34, 37, 41) have either artifically inoculated this grass or have found it naturally infected in the field indicating its susceptibility to the virus.

The relationship of the various cultivated crop plants to the epidemiology of the virus is difficult to judge. Barley and rye (36) both have been found to be susceptible to the virus and moderately susceptible to the mites. Oats (36) has been found to be susceptible to the virus but not susceptible to the mites. Sorghum (13) was found to be susceptible to the mites but immune to mosaic. All varieties of wheat tested (36) proved to be very susceptible to both the mite and the virus. Corn (36) presented a variety of reactions, ranging from complete immunity to both mosaic and the mites to complete susceptibility to both of them. The reactions of the cultivated crop plants are summarized in Table 17 of the Appendix.

Oats is apparently of questionable importance in epidemiology because the highest production of oats occurs in the eastern third of Kansas where the lowest production of wheat occurs and where wheat streak mosiac virus thus far has never been widespread or severe.

Corn also can be considered of minor importance in epidemiology. This is due to its variable reaction to the virus, from the complete immunity to complete susceptibility. It is also considered of minor importance because the major corn areas and the major wheat areas, although overlapping slightly, are in different parts of the state, corn being grown primarily in the eastern third. Del Rosario (9), using known virus susceptible varieties, found that mites readily colonized on corn.

Sorghum is difficult to assess. It has been found to be immune to the virus but it has proven to be susceptible to the mites. Gibson (13) found mites could remain on sorghum for periods up to 26 days. The general areas of high sorghum production overlap considerably with areas of high wheat production especially in the South Central section of the state. Sorghum could be of major importance as an oversummering host for the mites. Mites could land on sorghum and remain there until the emergence of more suitable hosts (volunteer wheat) took place.

Barley is susceptible to both the virus and the mites (36). Hence, it becomes of more importance in epidemiology than the previously mentioned crop plants because it not only serves as a reservoir of the virus but also provides the mites a place where they can reproduce. Although the areas of highest barley production are different from the areas of highest wheat production, large quantities of barley are grown in the Central, South Central and Northwestern areas of the state where extensive acreages are sown annually to wheat. Barley is a winter annual. Hence, barley, like wheat, would have to be volunteer in the early summer to be of any great importance in the oversummering of the virus and mites. In the fall, however, barley fields could be important midway stops between wheat fields.

Rye is very similar to barley. It is also susceptible to both mosaic and mites (36) and is a winter annual. It differs from barley in the areas of highest production. In 1955, a drouth year, the South West, North Central, Central, South Central and South East areas of the state each harvested over 5000 acres.[1] Although the acreage harvested is less than that of barley, it cannot be overlooked in an epidemiological study because of the overlapping of areas of high production and because of the large rye acreage used for pasture which is often not harvested as grain.

Wheat is very susceptible to both mites and mosaic (36). Its susceptibility can readily be seen through the losses suffered by Kansas farmers. In 1949 the loss was estimated to be $30,000,000 (28). The 1951 crop was damaged to the extent of $13,000,000 (11) and the 1954 crop loss was estimated at $14,000,000 (35). The role of wheat in epidemiology is readily seen. With no wheat, no epidemic of economic consequence is possible, but Kansas without wheat is difficult to imagine. The role of volunteer wheat in epidemiology is undoubtedly of major importance (4, 13, 36, 41).

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[1]Figures taken from, The 39th Report of The Kansas State Board of Agriculture. Topeka, Kansas, 1956.

Other crop plants have been found naturally infected in the field. These include oats, barley and rye. Although no appreciable loss occurred in these fields, many diseased plants were discovered (17). Natural infection indicates that both the mites and the virus are able to persist in these crops and also indicates their possible importance in the epidemiology of the virus. Several of the cultivated crop plants were previously considered in this discussion to be of minor importance but under especially favorable circumstances could probably achieve major importance.

The relative importance of the native grasses which are either susceptible or symptomless carriers is difficult to assess. It appears as though there are 6 main criteria in evaluating the importance of the native grasses. These are: (a) Are mites able to reproduce on these grasses and if so, to what degree? (b) Is the grass susceptible to the virus? If not susceptible, it can be of no importance as a virus reservoir. (c) Is the grass found naturally infected in the field? Natural infection suggests that both the mites and virus find these grasses to be suitable hosts in the absence of the preferred hosts. (d) What is the habit of the plant? Perennials appear to be of the greatest importance, affording not only a means for the virus and the mites to oversummer until the appearance of planted or volunteer wheat but they also serve as a means of perpetuating the virus from year to year, especially during adverse conditions. Annuals lack the year to year perpetuating ability but are able to allow the virus and mites to oversummer on them. Winter annuals could not serve either as an oversummering means or as a year to year means of perpetuating either the virus or the mite. Their importance then must be in the winter as overwintering hosts and in the fall and spring of the year when mite activity is high. Under these conditions they could be important in the spread of the virus from field to field in the fall and spring. If they emerge early, they could serve as partial oversummering hosts also. (e) In how many counties have these susceptible grasses been collected? If a grass is found in only a few counties, its importance in the epidemiology must be minor. If found in many counties it could be of major importance in the spread of the virus. (f) What is the relative abundance of the grass in counties where it has been found? If the grass can be found only infrequently, it can be of no major importance, however, if the grass is abundant it then can become of major importance in the spread of the virus.

With these criteria in mind, the grasses that are susceptible to the virus have been placed into three classes: those of major, those of minor and those of questionable importance. These grasses are listed and summarized in Tables 18, 19 and 20 of the Appendix. These classes are not intended to be rigid and it is conceivable that with more information, some of these grasses could change from one class to another.

Grasses Which Could Be of Major Importance In Epidemiology. Following is a discussion of the individual grasses which have been found to be susceptible to the virus and have been placed in the class of grasses which could be of major importance in the epidemiology of wheat streak mosaic virus.

Aeiglops cylindrica Host. This grass commonly called jointed goat grass, has been found naturally infected in the field by McKinney (34). Although collected in only 23 counties, conversation with Mr. C. O. Johnston, U.S.D.A., A.R.S., Field Crops Research Division at Kansas State Univeristy, has indicated this grass is spreading throughout Kansas. In the counties where collected, it is considered an "abundant" grass. Mites have a "fair-good" reproduction rate on this grass as found by Connin (5). Although this grass is an annual and does not serve as a means of year to year survival of either the mites or the virus, it does serve as a means of oversummering for both mites and the virus. This could become a major importance in an area if volunteer wheat were absent. The known Kansas distribution of jointed goatgrass can be seen in Plate I, Figure 1. The plates presented here are after Gates (12). They have been revised with the help of Hulbert[1] to include recent additions to the Kansas State University herbarium since his publication.

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[1]Present curator. Dr. Lloyd Hulbert, Assistant Professor of Botany, Kansas State University, Manhattan, Kansas.

<u>Bouteloua hirsuta</u> Lag. Commonly known as hairy grama, was included in the class of major importance because of the mites ability to reproduce well (5) on this grass. It was also placed in this class because it is "abundant" in the 71 counties (Plate I, Figure 2) where it has been collected. It is also a perennial grass which indicates that it not only provides an oversummering host for the mites and the virus but also provides a year to year perpetuation of both, especially during periods of adverse conditions.

<u>Cenchrus pauciflorus</u> Benth. This was a difficult grass to classify. It has been collected in 88 counties (Plate II, Figure 1) of the state. In these areas it is considered an "abundant" grass occurring especially in sandier areas. Sill and Connin (34) reported the occurrence of natural infection in sandbur. Connin (5) reported "good" mite reproduction and noticed that this grass is a symptomless carrier. Staples and Allington (41) reported that the sandbur in nature was not found to be a host of the mite, however, they noted that Connin (5) worked with seedlings whereas they examined mature plants. It is generally agreed (5, 36, 41) that the stage of maturity of a grass species may influence its susceptibility as a host of the mites and virus. It appears as though sandbur may be of importance in the spread of the virus when young but as the grass matures it may become of less importance.

<u>Elymus canadensis</u> L. Canada wildrye is "abundant" in the 97 counties (Plate II, Figure 2) where it has been collected.

## EXPLANATION OF PLATE I

Figure 1. Known distribution of *Aegilops cylindrica* Host. in Kansas. Supported by herbarium specimens.

Figure 2. Known distribution of *Bouteloua hirsuta* Lag. in Kansas. Supported by herbarium specimens.

# PLATE I

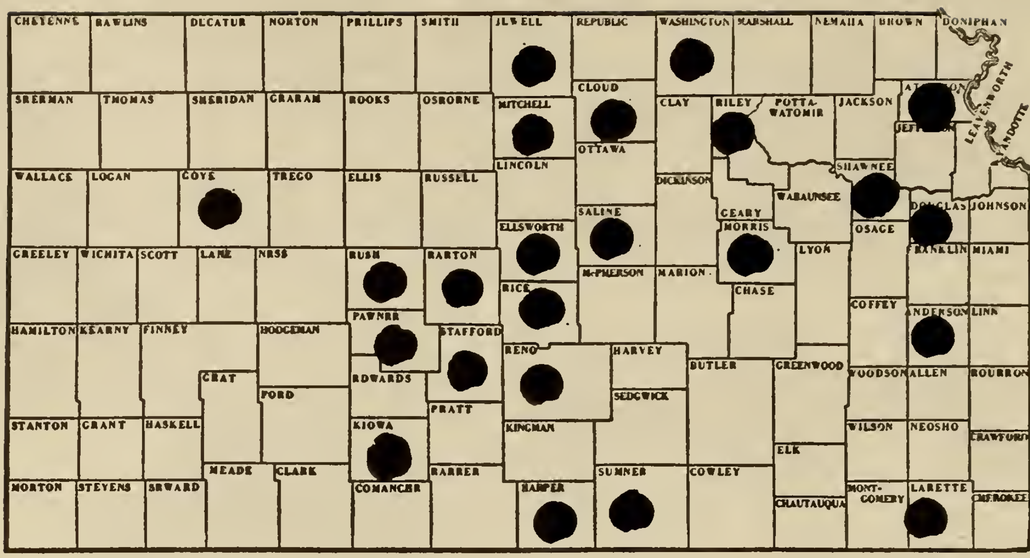


Figure 1

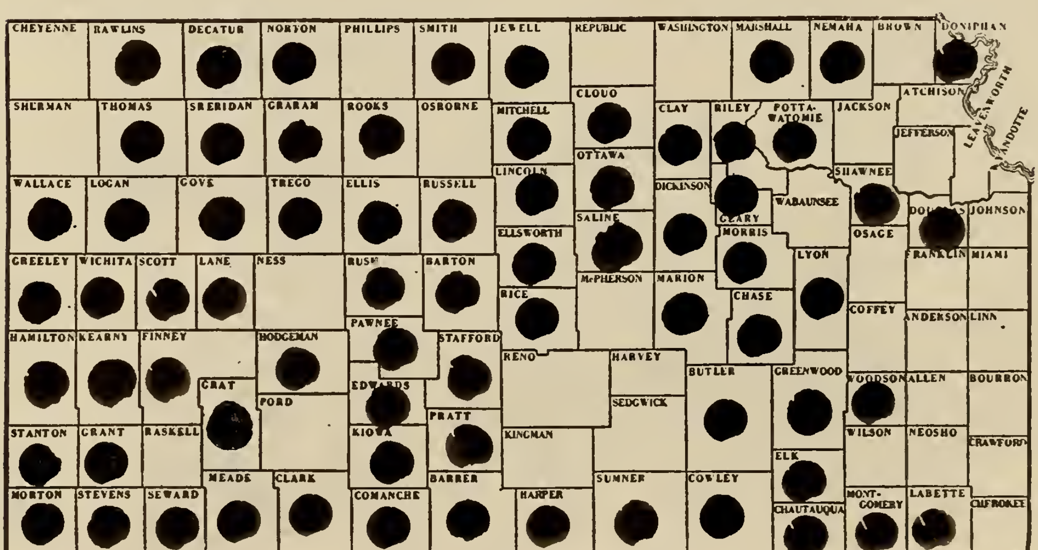


Figure 2

EXPLANATION OF PLATE II

Figure 1. Known distribution of *Cenchrus pauciflorus* Benth. in Kansas. Supported by herbarium specimens.

Figure 2. Known distribution of *Elymus canadensis* L. in Kansas. Supported by herbarium specimens.

PLATE II

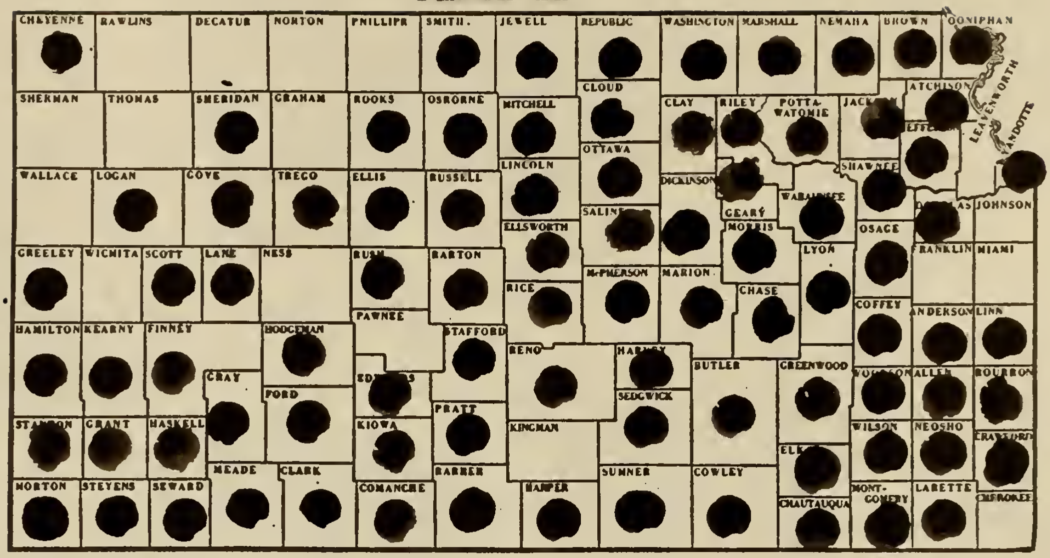


Figure 1

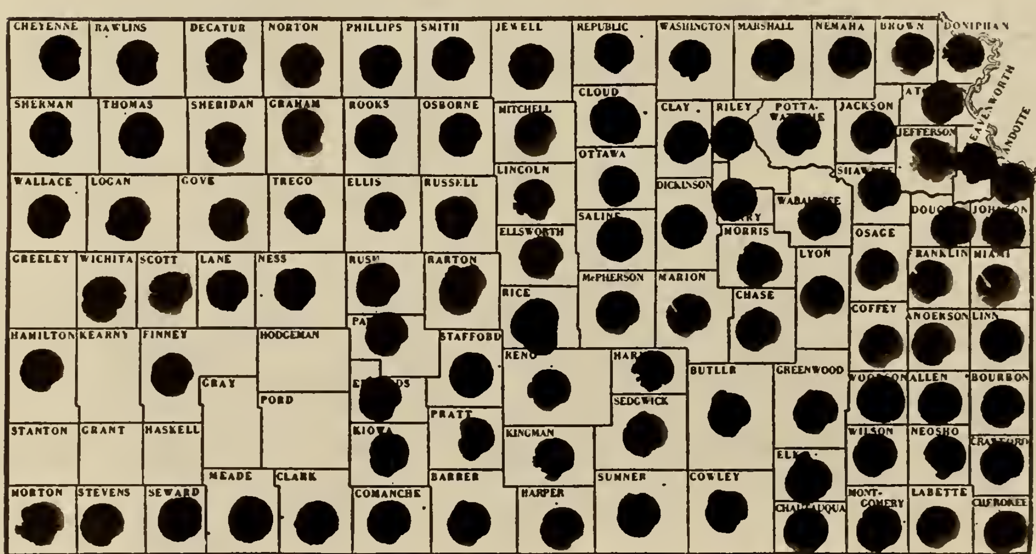


Figure 2

Being a perennial it could be an important means of perpetuating the virus through adverse conditions. Slykhuis (41) was unable to obtain mite survival on this grass and suggested that strain differences in the mite, A. tulipae (K.), accounted for this host specificity. Connin (5), however, was able to transfer mites from wheat to Canada wild rye and then back to wheat again. While on the Canada wildrye the mites had a "fair" reproduction rate. This grass must be considered potentially important because of its being wide spread and apparently having some qualities which favor mite reproduction.

Setaria viridis (L.). Green foxtail was first found naturally infected by Fellows as reported by Sill and Connin (34). It has been reported to be susceptible by Slykhuis (37) in greenhouse experiments. Two samples of S. viridis were found naturally infected in the field by the author during June, 1957 in Yuma County, Colorado and Dundy County, Nebraska. The wide distribution of this grass (Plate III, Figure 1) throughout the counties where it has been collected indicates the importance of this grass to epidemiology. Although an annual, the ease with which this grass is found naturally infected indicates it is readily infected in the field. Connin (5) found that mites had "good" reproduction on this grass. Its flowering habit from July to September in Kansas (12) indicates that this grass is young at the time of wheat harvest and ready for invasion by the mites and should provide a "good" host for buildup of both mites and virus in the absence of volunteer wheat.

Grasses of Questionable Importance in Epidemiology. Other grasses which have been found susceptible to the virus have been placed in the class of grasses of questionable importance in the epidemiology of wheat streak mosaic virus. These grasses are discussed below.

Bromus japonicus Thunb. McKinney as quoted by Sill and Connin (34) reported finding Japanese chess naturally infected in the field. Herbarium specimens have been collected from 43 counties (Plate III, Figure 2) and it is an "abundant" grass in these counties. Although an annual, this information would suggest that Japanese chess could be of major importance. It has been placed in this class (questionable), as were many others, because it is not known as yet whether mites are able to reproduce on this grass. This grass may be placed in the class of major importance should it prove to have "fair" or "good" mite reproduction potentialities.

Bromus secalinus L. Cheat was placed in this questionable class because of its unknown mite reproduction potential. It is an annual that has been collected in 43 counties (Plate IV, Figure 1). This grass probably would remain in this class even if it later proves to be a "good" mite host because it occurs only "infrequently" even in these counties where it has been collected.

Bromus tectorum L. Slykhuis, quoted by Sill and Connin (34), infected in the field. It is an annual that has been collected in 32 Kansas counties (Plate IV, Figure 2). It is

## EXPLANATION OF PLATE III

Figure 1. Known distribution of *Setaria viridis* (L.) in Kansas. Supported by herbarium specimens.

Figure 2. Known distribution of *Bromus japonicus* Thunb. in Kansas. Supported by herbarium specimens.

# PLATE III

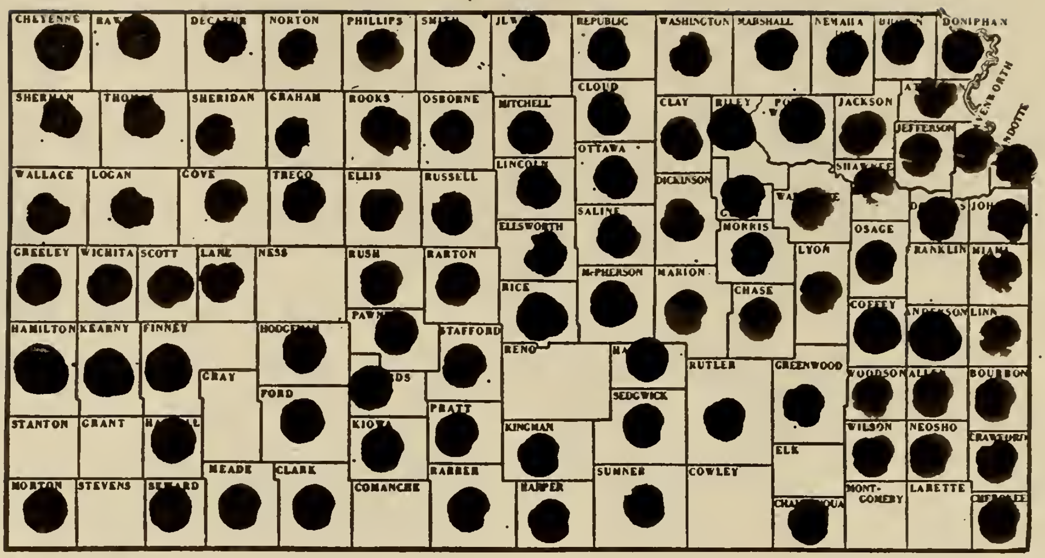


Figure 1

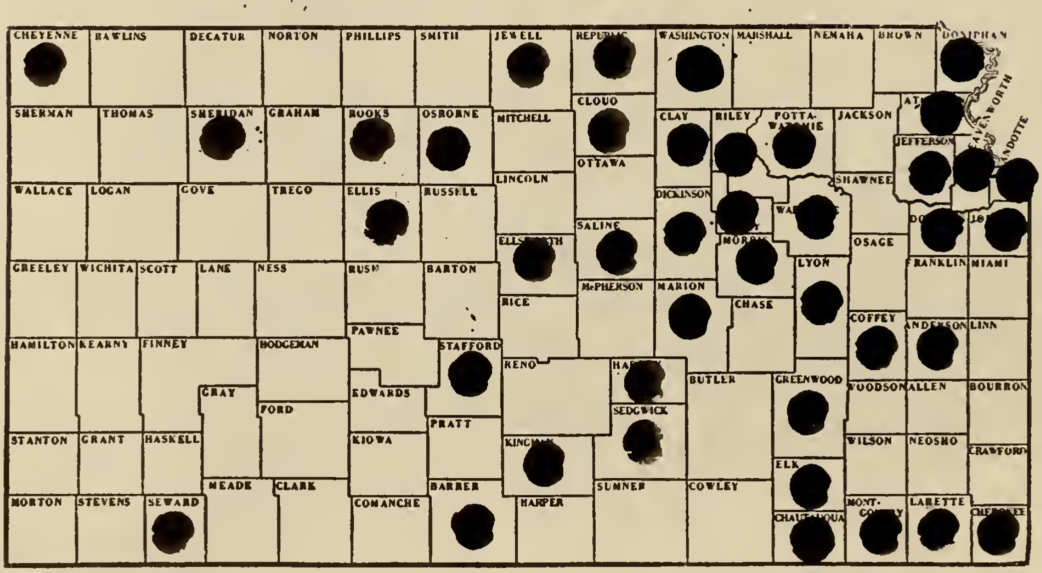


Figure 2

## EXPLANATION OF PLATE IV

Figure 1. Known distribution of *Bromus secalinus* L. in Kansas. Supported by herbarium specimens.

Figure 2. Known distribution of *Bromus tectorum* L. in Kansas. Supported by herbarium specimens.

PLATE IV

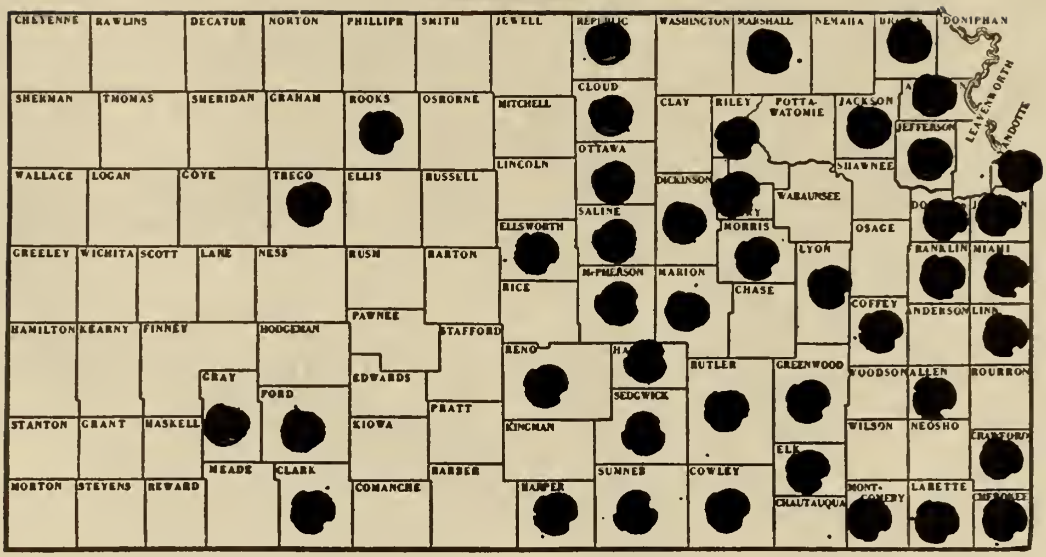


Figure 1

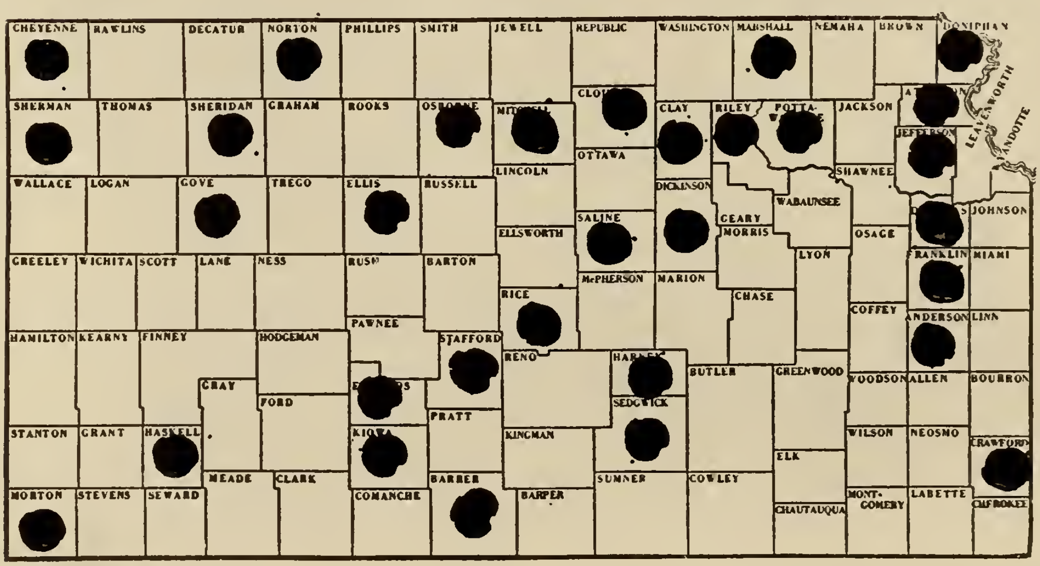


Figure 2

considered an "abundant" grass in these counties. The reason for placing this grass in the questionable category can be seen from Connin's report (5) that no mite reproduction occurred on this grass. Being naturally infected, it could possibly serve as a reservoir of the virus but as it provides no means for the buildup of mite populations, its importance in relation to epidemiology is questionable.

Digitaria sanguinalis (L.) Crabgrass is an annual which occurs "abundantly" in the 77 counties where it has been collected (Plate V, Figure 1). Its occurrence is well known by those who have attempted to grow a crabgrass free lawn. Connin (5) found that the mites reproduce "very poorly" on this grass. Hence, it was placed in the questionable class.

Echinochloa crusgalli (L.) Beauv. Barnyard grass, an annual, was placed in this class because it is not known if mites are able to reproduce on this grass. It has been reported as occurring naturally infected in the field by Slykhuis, as reported by Sill and Connin (34) indicating that mites may feed upon this grass. It has been collected in 55 counties (Plate V, Figure 2) but it is not an "abundant"[1] grass. It could become of major importance, even though "intermediate" in abundance, should it prove to be a "good" host for mite reproduction.

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[1]Terms chosen ("abundant", "intermediate" and "infrequent") are merely aids for classification.

EXPLANATION OF PLATE V

Figure 1. Known distribution of *Digitaria sanquinalis* (L.) in Kansas. Supported by herbarium specimens.

Figure 2. Known distribution of *Echinochloa crusgalli* (L.) in Kansas. Supported by herbarium specimens.

# PLATE V

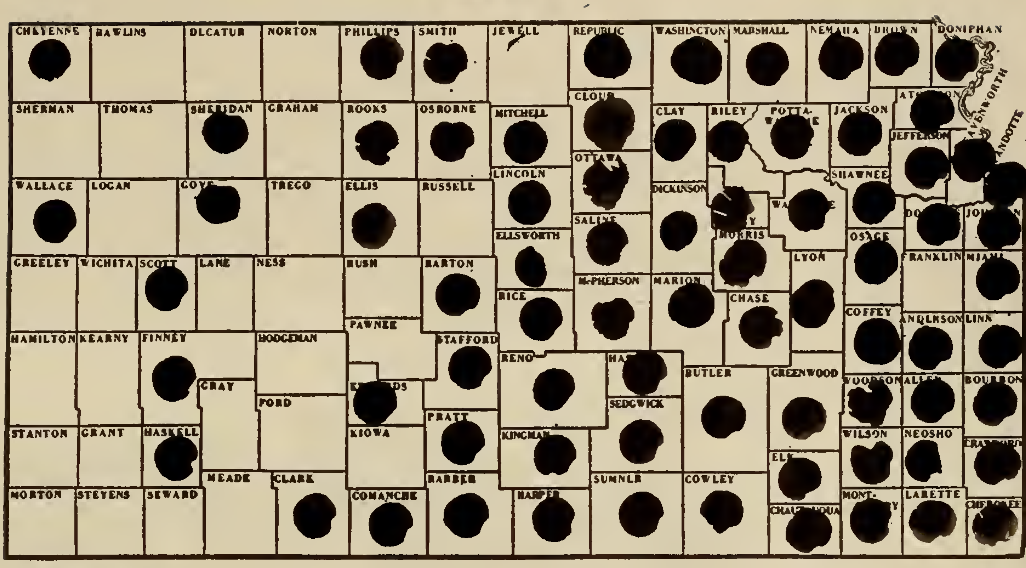



Figure 1

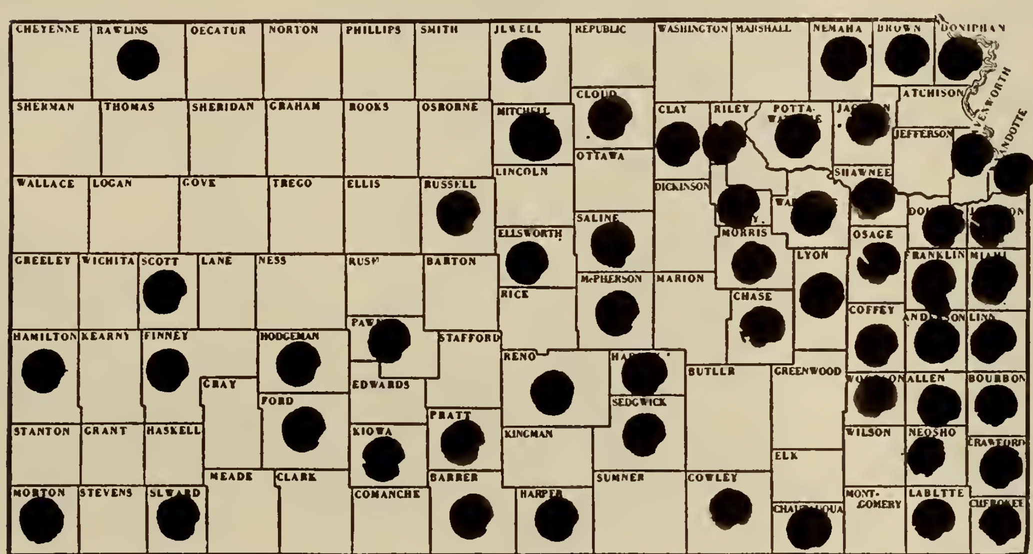



Figure 2

_Elymus virginicus_ L. Although only of "intermediate" abundance in the 70 counties where collected (Plate VI, Figure 1), it could be of major importance. It was placed in the questionable class because of a lack of knowledge regarding the reproduction potential of mites on this grass. Being a perennial it serves as a year to year means of perpetuating the virus through adverse conditions. McKinney, as quoted by Sill and Connin (34) reported finding Virginia wildrye naturally infected in the field. Since it is a close relative of _E. canadensis_, which has previously been considered of major importance, it may be placed in the class of grasses of major importance when its mite reproduction potentials are known.

_Eragrostis cilianensis_ (All.). This annual, although it was reported to be naturally infected by Slykhuis, as reported by Sill and Connin (34), will apparently remain in the questionable class because of its "poor" mite reproduction potentialities. If it were not for this fact stinkgrass would probably be considered of major importance, as it is so widespread. It has been collected in 104 counties (Plate VI, Figure 2) where it is considered an "abundant" grass. Dr. Lloyd Hulbert (personal conversation) has suggested that the grass probably occurs in the lone county (Ness) where it has not been collected.

_Eragrostis trichodes_ (Nutt.). Sand lovegrass will probably remain in the questionable class even when the reproductive potential of the mite becomes known because, although a

EXPLANATION OF PLATE VI

Figure 1. Known distribution of Elymus virginicus L. in Kansas. Supported by herbarium specimens.

Figure 2. Known distribution of Eragrostis cilianensis (All.) in Kansas. Supported by herbarium specimens.

# PLATE VI

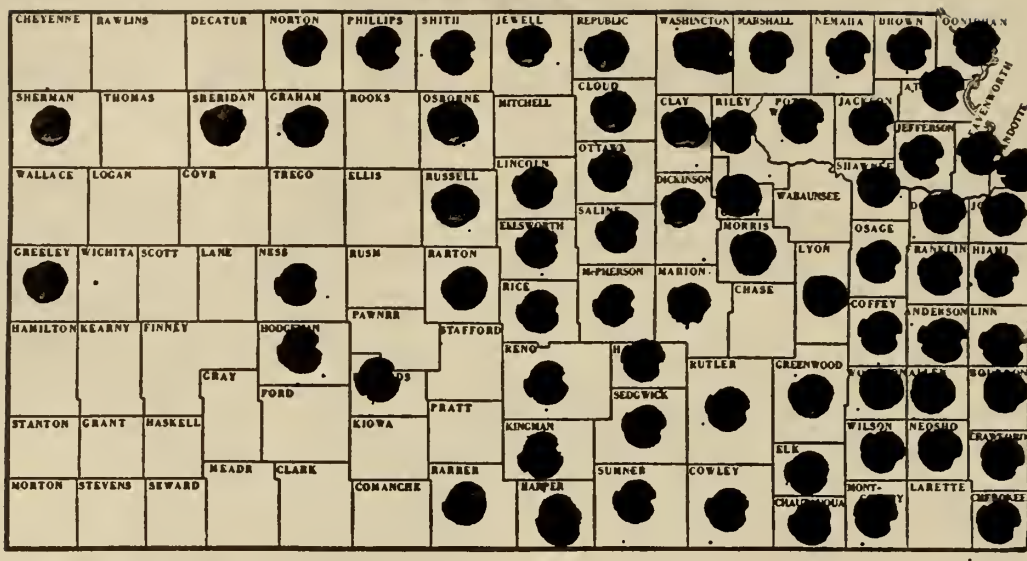



Figure 1

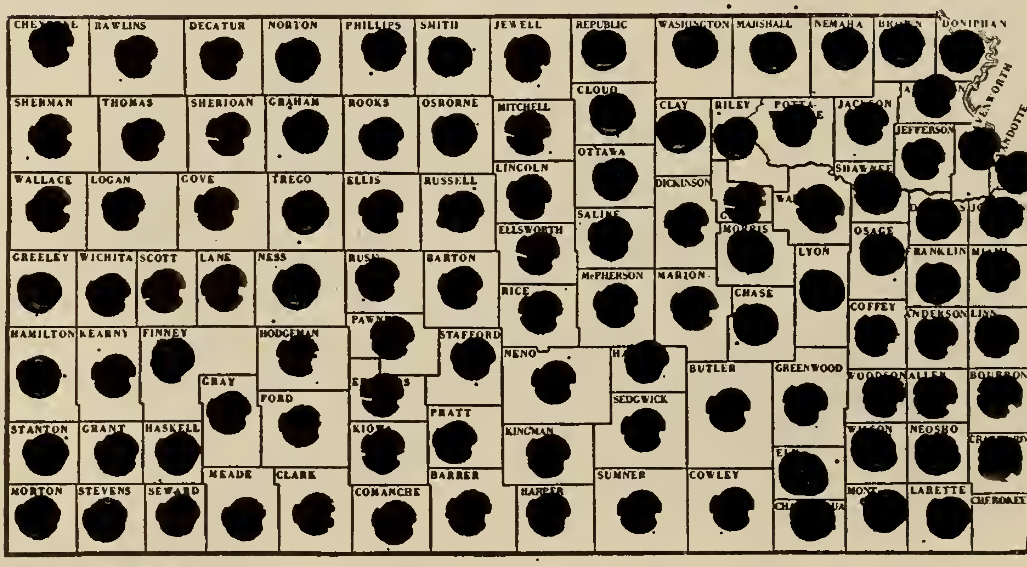



Figure 2

perennial, it occurs "infrequently" in the 31 counties where collected (Plate VII, Figure 1).

*Panicum capillare* L. Ticklegrass was difficult to classify. It is considered an "abundant" annual in Kansas, having been collected in 103 counties (Plate VII, Figure 2). Connin (5) reported that no mite reproduction takes place on this grass yet it was found naturally infected in the field by Sill (34). This indicates that the mites are able to feed on this grass. It is possible that grasses like *P. capillare* serve as temporary stopping places for mites. If true, mites blown onto ticklegrass in the summer and fall would be able to feed and, perhaps, then be blown to wheat fields where not only infection from the virus would take place but also reproduction of the mite could occur.

*Panicum dichotemiflorum* Michx. Fall panicum will probably remain of questionable importance. Its mite reproductive potentialities have yet to be tested but this annual is only found "infrequently" in the 72 counties where collections have been made (Plate VIII, Figure 1). It was not placed in the minor class because it has been found occurring naturally infected by Sill (34).

*Sitanion hystrix* (Nutt.). Squirreltail, as it is commonly known, occurs "infrequently" in the 29 Kansas counties where collected (Plate VIII, Figure 2). It was reported by Sill (34) as occurring naturally infected in the field. This field

## EXPLANATION OF PLATE VII

Figure 1. Known distribution of _Eragrostis trichodes_ (Nutt.) in Kansas. Supported by herbarium specimens.

Figure 2. Known distribution of _Panicum capillare_ L. in Kansas. Supported by herbarium specimens.

# PLATE VII

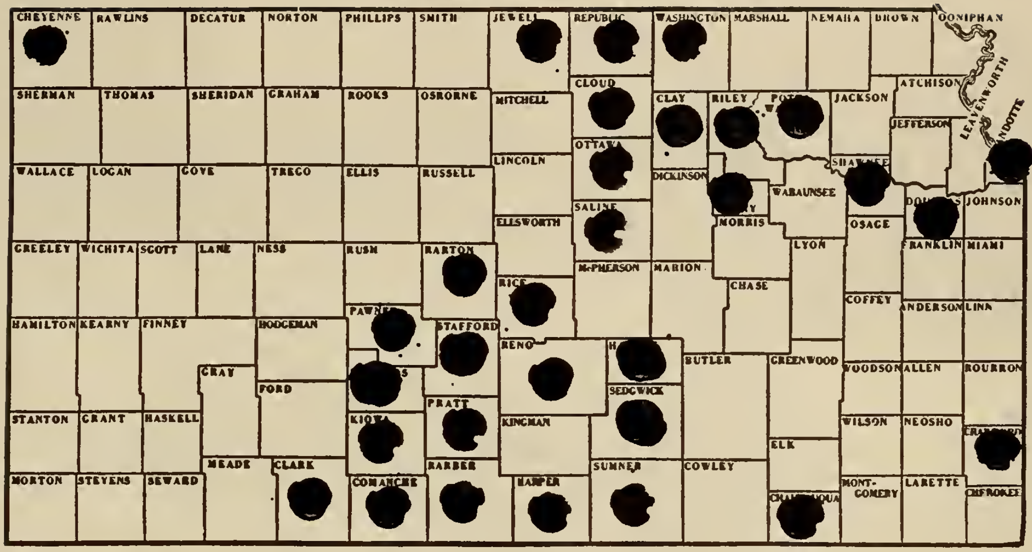



Figure 1

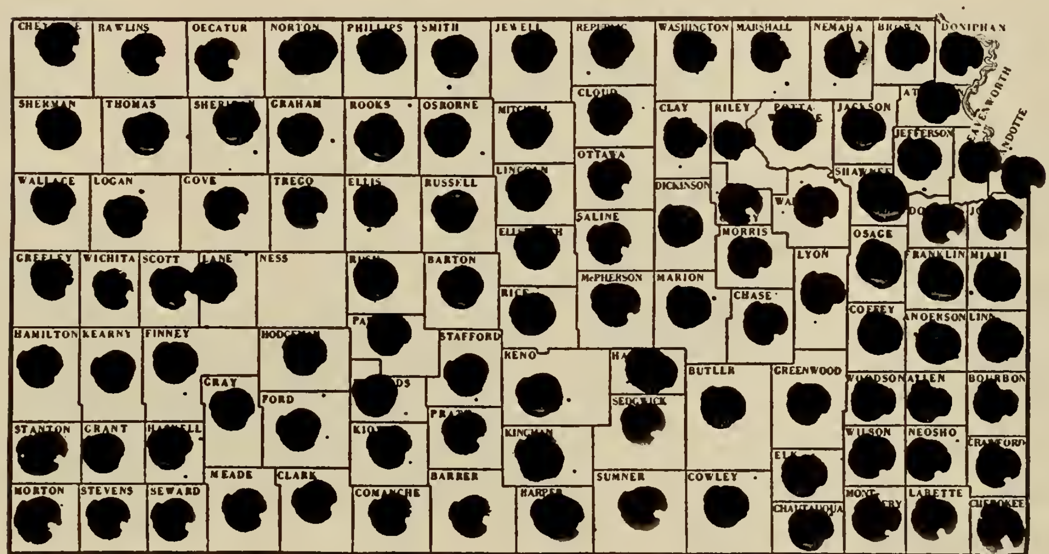



Figure 2

EXPLANATION OF PLATE VIII

Figure 1. Known distribution of _Panicum dichitomiflorum_ Michx. in Kansas. Supported by herbarium specimens.

Figure 2. Known distribution of _Sitanion hystrix_ (Nutt.) in Kansas. Supported by herbarium specimens.

PLATE VIII

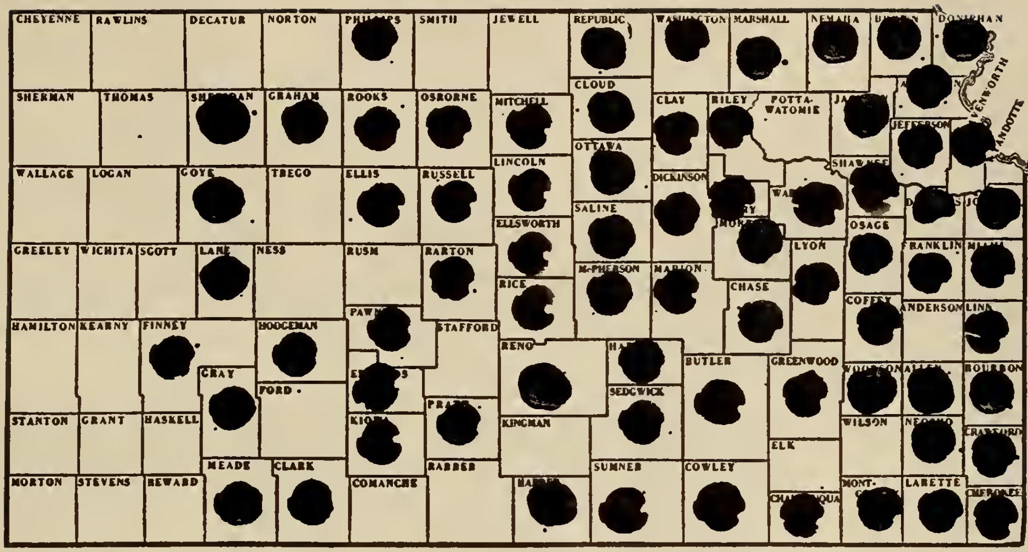



Figure 1

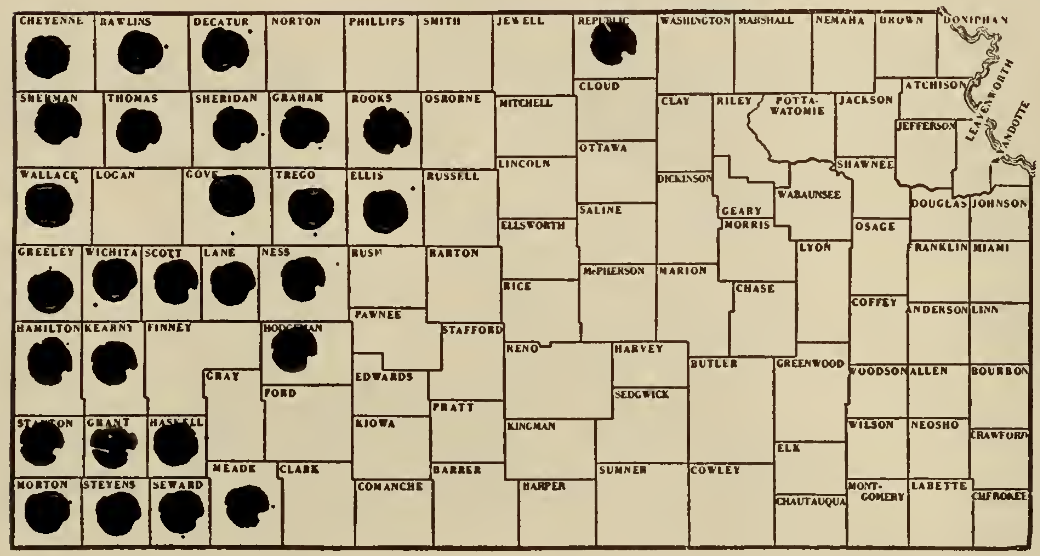



Figure 2

report was confirmed during the course of the present experiments by the author. Being a perennial, it could serve as a means of virus survival during drouth years when volunteer wheat and even planted wheat is sparce or absent. It will probably remain in the questionable class because of its "infrequent" occurrence. Its scarcity can be attested to by the difficulties encountered by the author in attempting to obtain seeds. One packet of seeds received was subsequently identified as Hordeum jubatum L. Several searches of areas where it was thought to occur produced no results. Seeds were later received from the Regional Plant Introduction Station at Pullman, Washington which were identified as S. hystrix.

Sporobelus airoides (Terr.). In the previously described experiments the author found that alkali sacaton was a symptomless carrier of the virus. Although a perennial, it can be considered of questionable importance for two reasons. First, it is not known if the mites are able to reproduce on this grass. Second, the grass has been collected in only 21 counties (Plate IX, Figure 1) of Kansas where it occurs "infrequently".

Sporobelus cryptandrus (Terr.). Sand dropseed was also found by the author to be a symptomless carrier during the previously described experiments. This perennial grass could become of major importance as it occurs "abundantly" in 81 counties (Plate IX, Figure 2). Unfortunately, as yet it is not known whether the mites have the ability to reproduce on this grass.

EXPLANATION OF PLATE IX

Figure 1. Known distribution of *Sporobolus airoides* (Torr.) in Kansas. Supported by herbarium specimens.

Figure 2. Known distribution of *Sporobolus cryptandrus* (Torr.) in Kansas. Supported by herbarium specimens.

PLATE IX

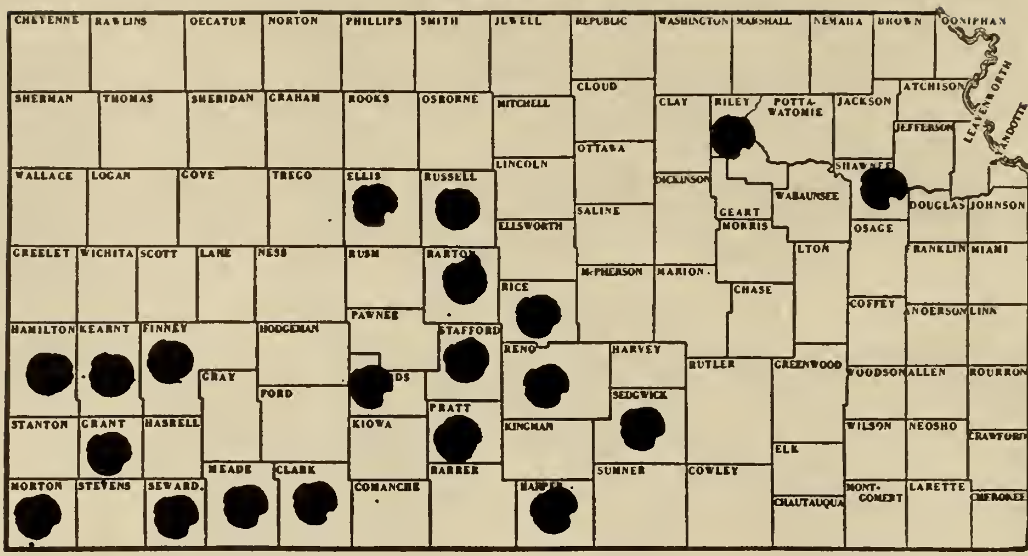



Figure 1

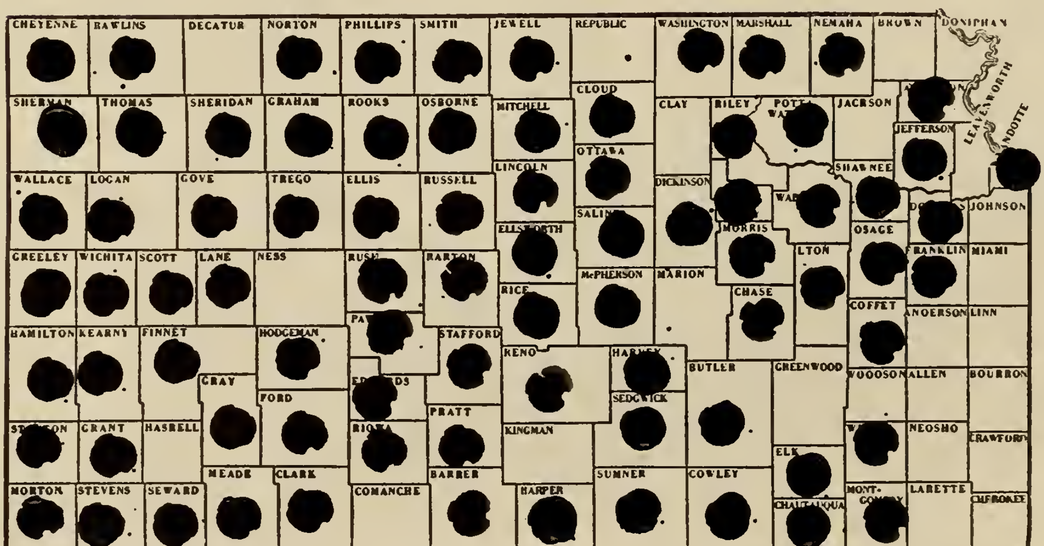



Figure 2

Sporobolus neglectus Nash. This annual grass, dropseed, has been found only "infrequently" in the 40 Kansas counties in which collections have been made (Plate X, Figure 1). Its susceptibility was found during these host range studies. The mite reproduction potential is unknown. Because of its "infrequent" occurrence it is doubtful if this grass could be of major importance even if it should prove to be a good host for mite reproduction.

Grasses of Minor Importance in Epidemiology. Other virus susceptible grasses were placed in a class of minor importance to the spread of the virus. None of these grasses have been found naturally infected in the field. This does not mean that there is no possibility of finding a plant naturally infected but, due to other reasons, the possibilities of finding a naturally infected grass in this group are reduced.

Digitaria ischaemum (Schreb.). Smooth crabgrass was found by Connin (5) to have "fair-good" mite reproduction. This would not indicate the reasons for placing this grass in a minor class. Although it has not been found naturally infected, it was proven to be susceptible to the virus by McKinney and Fellows, as reported by Sill and Connin (34). This annual was placed in this class because of its "infrequent" occurrence in only 6 Kansas counties (Plate X, Figure 2), largely on lawns.

Oryzopsis hymenoides (Roem. and Schult.). This perennial grass was classified as being minor in importance because of the few collections which have been made of this grass

EXPLANATION OF PLATE X

Figure 1. Known distribution of *Sporobolus neglectus* Nash. in Kansas. Supported by herbarium specimens.

Figure 2. Known distribution of *Digitaria ischaemum* (Schreb.) in Kansas. Supported by herbarium specimens.

# PLATE X

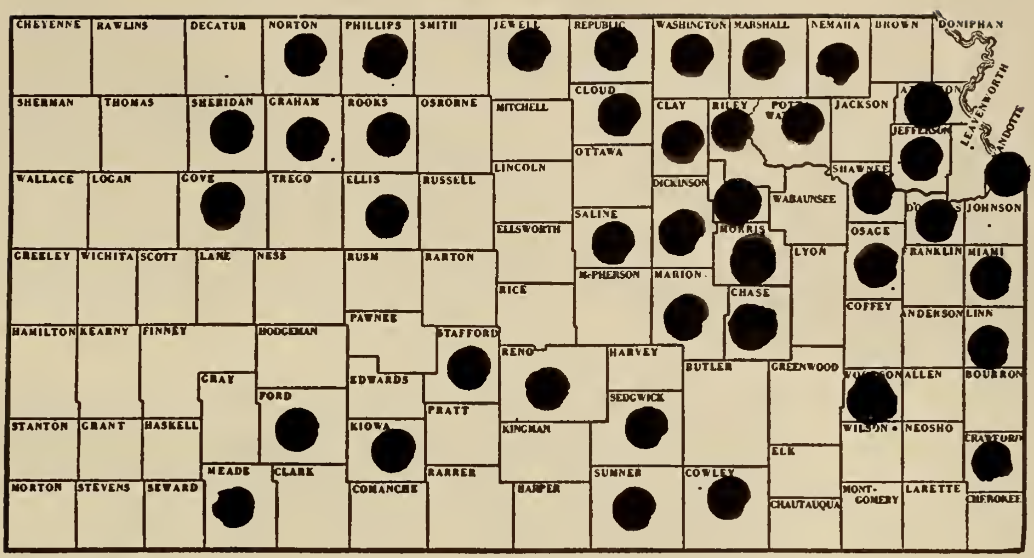



Figure 1

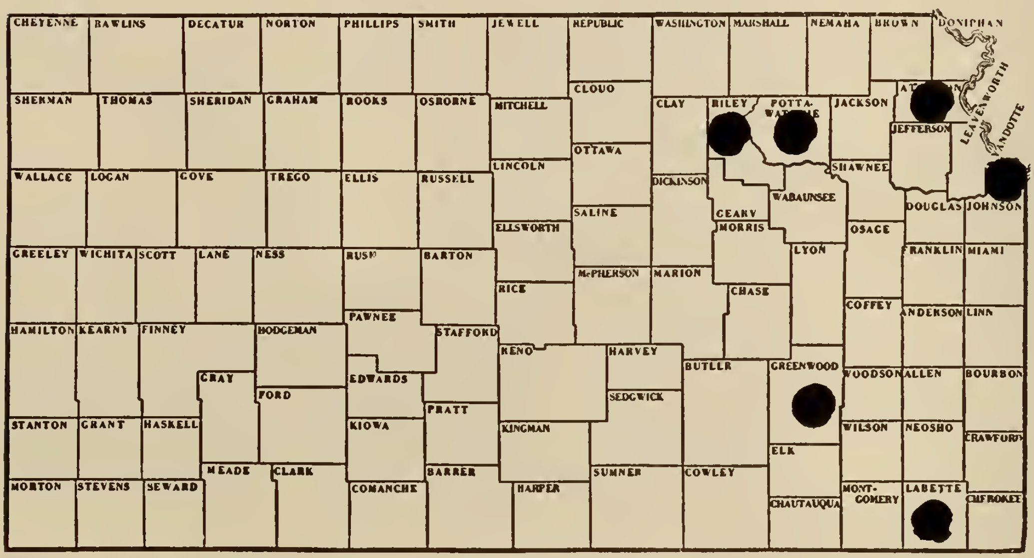



Figure 2

(Plate XI, Figure 1). The few counties where this grass has been found are located mainly in the northwestern part of the state. Even though occurring in areas of high wheat production, Indian ricegrass is found only "infrequently" in these counties. It was found to be susceptible by McKinney, as reported by Sill and Connin (34) but it has not yet been found occurring naturally infected in the field.

Poa bulbosa L. Very few plants of bulbous bluegrass have been collected in Kansas. Herbarium specimens have only been found in 2 counties (Plate XI, Figure 2) and it is only found "infrequently" in these counties. While it is not yet known if the mites are able to reproduce on this grass, it will apparently remain of minor importance for the above mentioned reasons. It also was found to be susceptible by McKinney as quoted by Sill and Connin (34).

P. compressa L. This perennial was found to be susceptible by McKinney, as reported by Sill and Connin (34). It has been collected in 12 counties (Plate XII, Figure 1) of eastern Kansas. At the present time the mite reproduction potential of Canadian bluegrass is unknown. It appears unlikely that this grass could achieve major or even questionable importance in the spread of the virus.

Setaria verticillata (L.) Bur bristlegrass was found to be virus susceptible by Slykhuis, as reported by Sill and Connin (34). It is an annual that is "infrequently" found in the 4 counties where it has been collected (Plate XII, Figure 2).

EXPLANATION OF PLATE XI

Figure 1. Known distribution of Oryzopsis hymenoides (Roem and Schult.) in Kansas. Supported by herbarium specimens.

Figure 2. Known distribution of Poa bulbosa L. in Kansas. Supported by herbarium specimens.

# PLATE XI

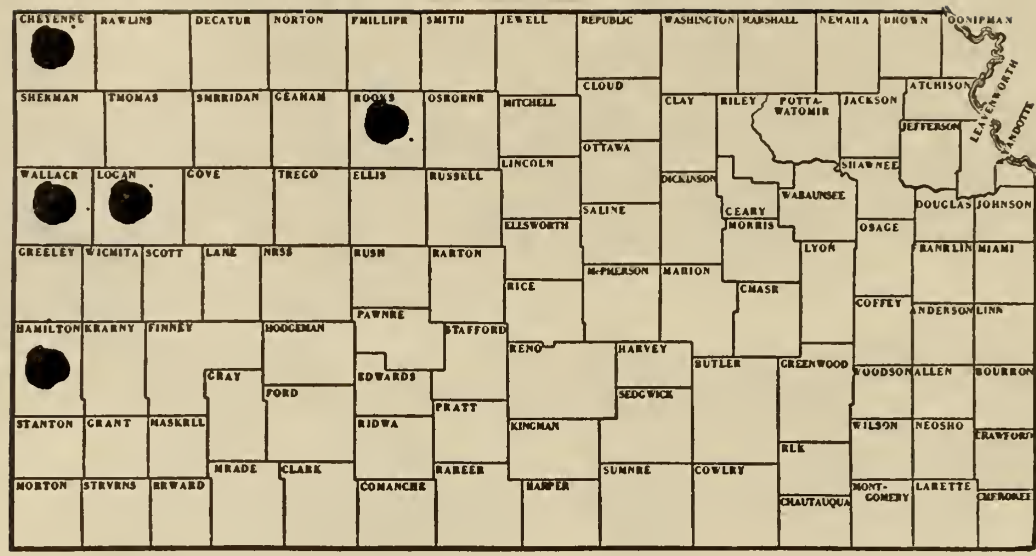



Figure 1

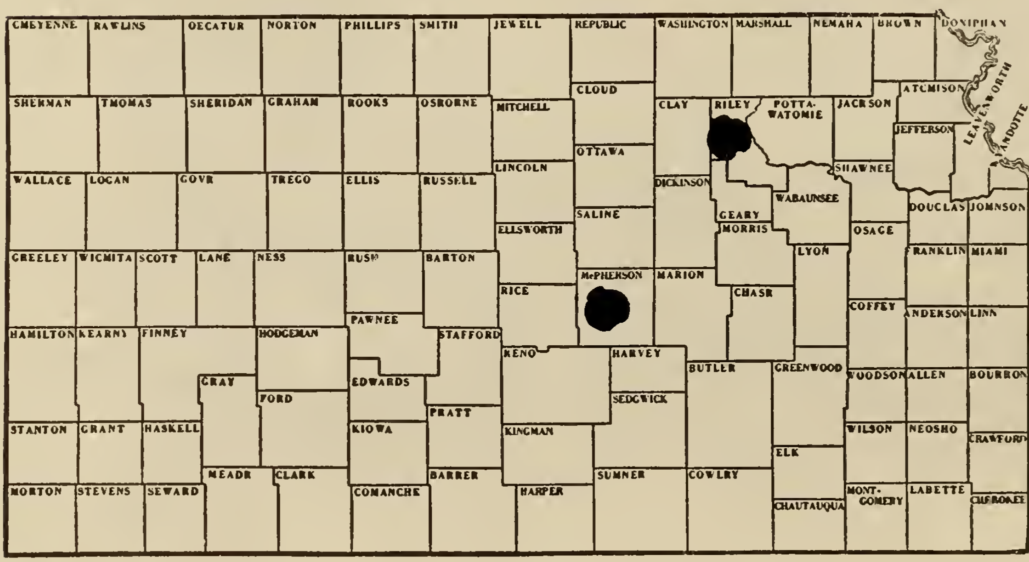



Figure 2

## EXPLANATION OF PLATE XII

Figure 1. Known distribution of *Poa compressa* L. in Kansas. Supported by herbarium specimens.

Figure 2. Known distribution of *Setaria verticillata* (L.) in Kansas. Supported by herbarium specimens.

PLATE XII

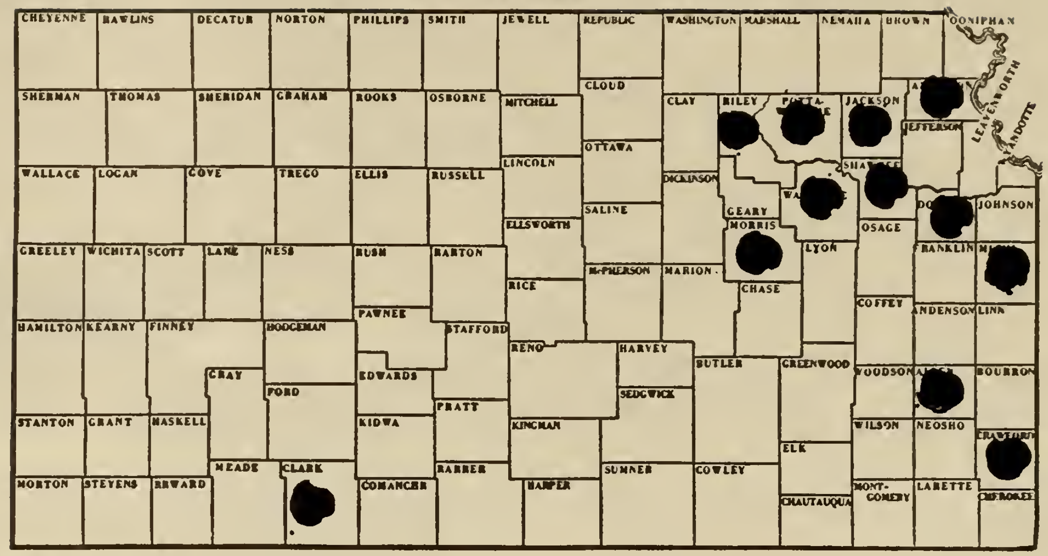



Figure 1

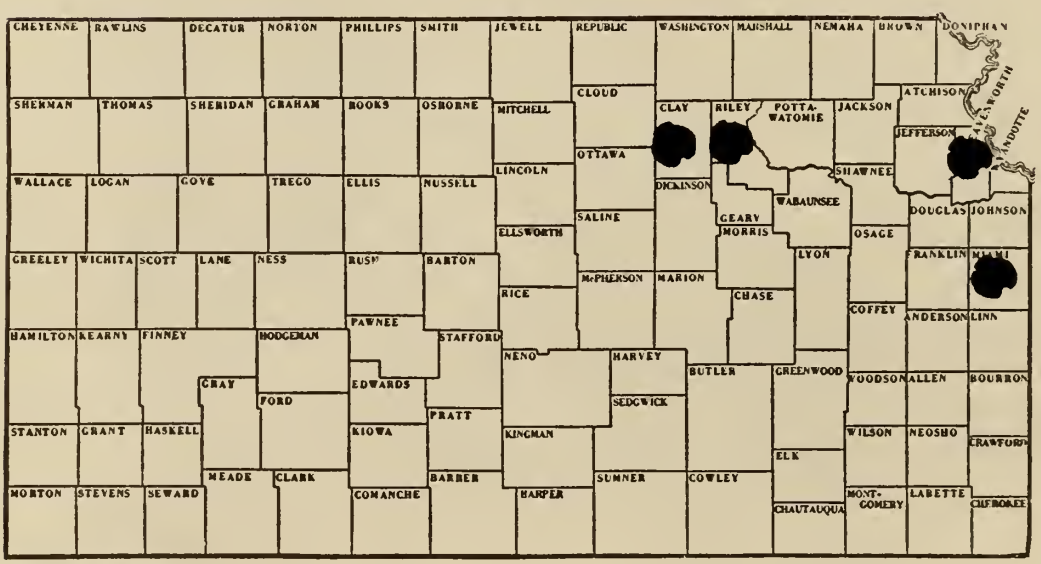



Figure 2

Although no one has tested this grass as to mite susceptibility, it apparently cannot be anything but of minor importance in epidemiology.

<u>Stipa robusta</u> Scribn. This narcotic (12) containing perennial grass has been collected in only 1 of Kansas' 105 counties (Plate XIII). It can be considered to be an "infrequent" grass in the state and also in Greely County where it was collected. It was reported to be virus susceptible by McKinney, as quoted by Sill and Connin (34). It is difficult to imagine sleepy grass obtaining major importance in epidemiology even if it should be found to have "good" mite reproduction qualities.

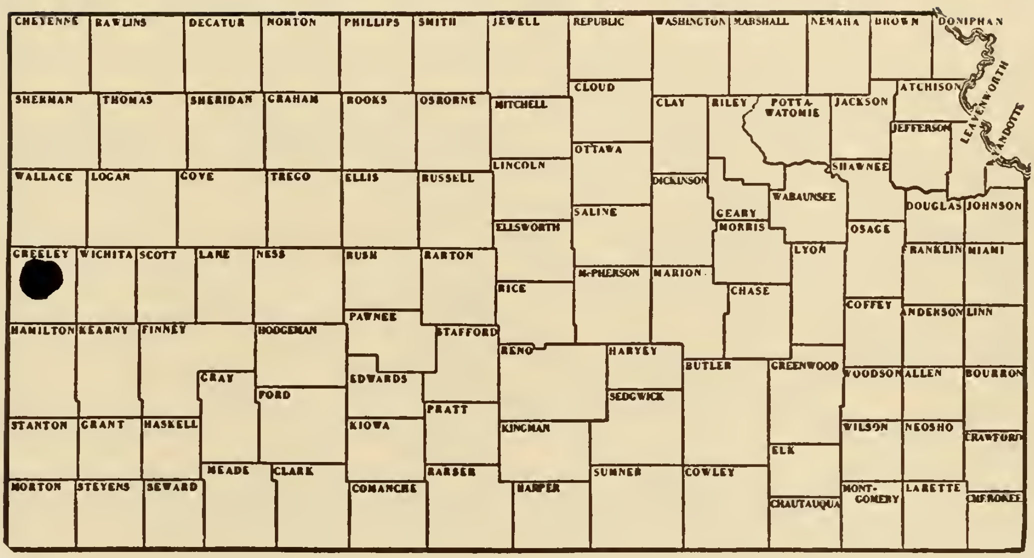
A general appraisal would point to wheat as the most important host of both virus and mites. There is, however, approximately a 2 1/2 month period (mid-June to September) from harvest until the emergence of fall planted wheat. How the mites and virus are able to maintain themselves through these periods and then are able to develop and spread in epidemic proportions has been a much debated question.

The role of volunteer wheat in relation to epidemiology has been studied (4, 13, 36, 41). Connin (4), in field observations, found that volunteer wheat which emerged at the time of harvest or shortly after harvest provided an excellent means of oversummering until the emergence of fall planted wheat. Staples and Allington (41) were able to show that volunteer wheat, readily produced by hail or lodging, could soon become infested with mites and be seriously infected with the virus.

## EXPLANATION OF PLATE XIII

Known distribution of *Stipa robusta* Scribn. in Kansas. Supported by herbarium specimens.

PLATE XIII


CHEYENNE
RAWLINS
DECATUR
NORTON
PHILLIPS
SMITH
JEWELL
REPUBLIC
WASHINGTON
MARSHALL
NEMAHA
BROWN
DONIPHAN
SHERMAN
THOMAS
SHERIDAN
GRAHAM
ROOKS
OSBORNE
MITCHELL
CLOUD
CLAY
RILEY
POTTA-WATOMIE
JACKSON
ATCHISON
JEFFERSON
LEAVENWORTH
WALLACE
LOGAN
GOVE
TREGO
ELLIS
RUSSELL
LINCOLN
OTTAWA
DICKINSON
GEARY
WABAUNSEE
SHAWNEE
DOUGLAS
JOHNSON
SALINE
ELLSWORTH
MORRIS
OSAGE
GREELEY
WICHITA
SCOTT
LANE
NESS
RUSH
BARTON
McPHERSON
MARION
LYON
FRANKLIN
MIAMI
RICE
CHASE
COFFEY
ANDERSON
LINN
HAMILTON
KEARNY
FINNEY
HODGEMAN
PAWNEE
STAFFORD
RENO
HARVEY
BUTLER
GREENWOOD
WOODSON
ALLEN
BOURBON
GRAY
EDWARDS
FORD
SEDGWICK
PRATT
STANTON
GRANT
HASKELL
KIOWA
KINGMAN
WILSON
NEOSHO
CRAWFORD
ELK
MEADE
CLARK
SUMNER
COWLEY
MORTON
STEVENS
SEWARD
COMANCHE
HARPER
CHAUTAUQUA
MONT-GOMERY
LABETTE
CHEROKEE

With the appearance of fall planted wheat, they found that the mites readily transmitted the virus from these areas of volunteer wheat into fields of planted wheat causing severe damage to these planted fields. Other authors have supported their contention (4,16). It is now certain that volunteer wheat, under these conditions, is a ready source of mite and virus for fall planted wheat.

This raises the question of what happens in the absence of volunteer wheat. As was mentioned earlier, other crop plants may also serve as hosts of both mites and virus. Barley and rye, being winter annuals in Kansas, have approximately the same growing season as wheat and may also serve as overwintering hosts and as volunteer plants they also are of importance in the oversummering of mites and virus. Rye was mentioned earlier as being harvested on over 5,000 acres in 5 of the 9 sections of the state. A closer examination of figures on acres planted against acres harvested of this crop reveals a slightly different picture. Approximately 3 to 4 times as much rye is planted as is harvested. The remainder, not harvested, is utilized by Kansas farmers as pasture. This provides many acres (195,000 in 1955) in the wheat growing areas where both mites and virus are able to persist. Sorghum, while apparently immune to the virus, is able to serve as a temporary host of the mites where they may remain for periods of up to 26 days (13). From these plants they may be blown to hosts which are not only suitable for mites but also for the virus. Because of the variable reaction of corn to both mites and the virus, its importance to epidemiology is questionable (Table 8 of the Appendix).

Under prelonged drouth conditions good oversummering volunteer plants of cultivated crops may be sparse or absent. Under these conditions the native grasses probably become of major importance in the survival of the virus and mites. The native grasses may be infected under normal conditions and help in the spread of the virus but their major importance is apparently in their ability, especially the perennials, to maintain not only themselves but also both mites and virus through these periods of adverse weather conditions and serve as a source for both when conditions become favorable again for volunteer grain.

## THE ROLE OF INSECTS AND MITE VECTOR IN EPIDEMIOLOGY

### Review of Literature

Vector search. Many intensive studies were conducted before a vector of the wheat streak mosaic virus was discovered. The search was complicated by the large number of different insect and mite species often found in a wheat field. The greenbug, *Texoptera graminum* (Rond.), was reported as a vector by Atkinson (2) until experiments by Slykhuis (38), Harvey (18) and Connin and Staples (7) proved otherwise. Harvey (18) tested many genera and species of insects as possible vectors. The insects he tested are given in Table 21 of the Appendix. He reported some evidence for transmission of the virus by the following insects: Endria inimica (Say), Meromyza americana Fitch and Rhopalosiphum subterraneum Mason. In other cases he apparently obtained transmission of the virus when a mixture of genera was present. Connin and Staples (7) also tested various insects found associated with diseased wheat plants. Insects tested, (Table 22 of the Appendix) included several that apparently transmitted the virus. These were M. americana and E. inimica. They suggested that perhaps these results were obtained because of accidental contamination or overlooking the presence of the true vector. In 1953 Slykhuis (39) found that the Eriophyid mite, Aceria tulipae (Keifer), was a vector of the disease. These results were confirmed by Del Rosario (8) and by Connin and Staples (7). The latter found the mite could pass readily through screen and cloth barriers. They said "Consequently cases of transmission of the wheat streak-mosaic virus reported in the literature could have resulted from the unknown presence of this eriophyid, particularly where diseased wheat collected in the field was used as a virus source for the test insects". The mite has proven to be a very efficient vector (41). Del Rosario (8) tested 5 strains of the virus and reported the percentage of transmission ranging from 84.21 to 92 percent. All stages with the exception of the eggs can transmit the virus according to Slykhuis (36) but only nymphs apparently can acquire the virus (8, 36). Older adults have been unable to do so but can transmit the virus if obtained during the nymphal stages (8, 36).

Mites carrying the virus could transmit it for at least 6 days after feeding (36). Experiments by Del Rosario (8) with the most common strain of the virus found in Kansas, Marmor virgatum var. typicum McK. strain 1 (22) or M. virgatum var. typicum strain A (21), confirmed these results.

Mite characteristics. The small size of the vector, A. tulipae, was probably the most important factor contributing to the long search. The adult measures only 38 x 173 to 63 x 285 microns and the eggs average only 35 x 42 microns. The mite has an elongated, whitish, spindle or cigar-shaped body with 2 pairs of legs at the anterior end (20).

Staples and Allington in 1956 (41) found the average life cycle of the mite, under favorable greenhouse conditions of 75° to 78°F., to be as follows:

| | |
|---|---|
| Egg incubation period . . . . . . | 3 days |
| First nymph . . . . . . . . . . . | $1\frac{1}{2}$ days |
| First molt . . . . . . . . . . . | 3/4 day |
| Second nymph . . . . . . . . . . . | $1\frac{1}{2}$ days |
| Second molt . . . . . . . . . . . | 3/4 day |
| Egg hatching to adult . . . . . | 4 to 5 days |
| Preoviposition period . . . . . | 1 to 2 days |
| Complete cycle from egg to egg. . | 8 to 10 days |

Although the mites were isolated singly, all of the adults reared by these authors were females and produced eggs thus showing that parthenogenesis had occurred. At least 12 eggs were produced by each female under these favorable conditions. Keifer (20) reported that males of this species had not been recognized but now states that males, although scarce, can be found (personal correspondence with Gibson (13)). Slykhuis (36) found that mites and their eggs remained viable when exposed to extremely cold temperatures over various periods of time. He exposed infested wheat plants to a series of cold temperature changes to produce vernalization after which they were exposed to various sub-freezing temperatures for various lengths of time. Yogo wheat, exposed to -15°C. and -20°C. did not survive for 1 day yet he found that mites survived -15°C. for 2 days and the eggs remained viable when exposed to the same temperature for 8 days. Slykhuis (36) also pointed out that the mite perished sooner at lower humidities and higher temperatures. The mite survival was highest at 100 percent humidity at 5°C. and the lowest at 25 percent humidity and 25°C., under which conditions no mites were able to survive. Del Rosario (9) was able to prove that mites could survive near freezing temperatures for a minimum of 3 months.

Methods of dispersal. Slykhuis in 1955 (36), Pady in 1955 (30) and Staples and Allington in 1956 (41) showed that wind played a major role in the dispersal of mites. Slykhuis collected the mites on vaseline coated slides which were placed in the path of air blowing from a 10" fan over mite infested wheat growing in the greenhouse. Pady found mites upon smeared slides which were exposed on the top of Willard Hall on the Kansas State University campus. This building is approximately 150 feet high. The nearest wheat field was found to the south 1½ miles away. Staples and Allington used the familiar wind-vane type of trap. The mites were trapped on grease coated slides during the critical period when a wheat crop, if infected, would be seriously injured. Staples and Allington (41) also found that a windbreak of a double row of 20 feet trees and a deep vale in a wheat field offered no barrier to the spread of mites. Another method of mite dispersal, although it may play only a very minor role, was found by Gibson (15). This occurred when wheat plants which harbored large colonies of mites in the greenhouse became weak, chlorotic and finally necrotic. The mites then migrated to the uppermost parts of the plants. He observed aphids coming into contact with swarming masses of mites, which crawled up the legs of the aphids and could be observed crawling over their bodies. In experiments he found that mites became "hitchhikers" and by this manner he believed were occasionally transported by the aphids. Gibson (13) also tried to determine if raindrops were responsible for a limited spread of the mites. Statistical studies indicated that rain had little or no influence on their spread.

Del Rosario (9) was able to show that mites had the ability to walk. She found that mites travel fast at first and then apparently slow their pace, walking a distance of approximately 4 to 5 cm. per hour on a smoked glass slide.

Fellows (10) has shown that the green kernel and surrounding supporting tissues contain the virus but all reports indicate the virus is not seed transmitted (32). Gibson (14) discovered that it was possible for mites to move directly from germinating mite infested kernels to the developing seedlings. This experiment was conducted under simulated hail conditions. Hail often produces localized heavy stands of volunteer wheat when it causes lodging and shattering in nearly mature wheat (14, 41). He concluded that mites were able to move from a kernel directly to the new seedlings under certain specialized conditions. Staples and Allington (41) discovered that volunteer wheat, produced under hail conditions, can support large populations of mites. In field tests, it was discovered that the volunteer wheat, at the time of emergence of planted wheat, was heavily infested with mites and was also severely diseased. From these observations it appears logical to assume that the mites are able to transmit the virus directly from a maturing wheat plant to a seedling under these conditions, but workers (14, 41) have not been able to prove this assumption.

Hosts. Where the mite survives after harvest until the appearance of summer volunteer wheat has been the cause of much research with the native grasses. In 1954 Painter and Schesser (31) reported finding mites on western wheatgrass, *Agropyron smithii*. These were brought to the greenhouse and when transferred to wheat formed colonies on 12 out of 43 plants. In surveys made by Connin (6), small numbers of mites were found on western wheatgrass and occasional mites were found on Canada wildrye (*Elymus canadensis*), green foxtail (*Setaria viridis*) and smooth crabgrass (*Digitaria ischaemum*). Since he found fewer mites on these grasses than he did on early volunteer wheat, he came to the conclusion that these grasses are of much less importance than early volunteer wheat as oversummering hosts for the mites.

Connin (6) also tested many species of native grasses as well as varieties of wheat, corn, sorghum, barley and oats. On 12 of 24 species of native grasses (Table 13 of the Appendix), the mites reproduced. All varieties of grains tested also showed mite multiplication although the population increase varied greatly with the different plants, wheat and barley giving the highest rate of population increase. The most efficient oversummering host of the mite has been early volunteer wheat which emerges before or shortly after the harvest of seeded wheat (4, 6, 40). Staples and Allington in 1956 (41) and Gibson in 1957 (14) reported that hailstorms or lodging in maturing wheat produced early volunteer wheat. These localized stands of seedlings are soon large enough to be infested with colonies of mites even though the young volunteer plants are covered by maturing wheat plants. Under these conditions (hail or lodging with ample moisture available) Gibson (14) concluded that the mite moved directly from the older maturing wheat plants to the volunteer seedlings. He was, however, unable to prove that the virus moved by this process.

## Discussion

The search for a vector of wheat streak mosaic virus gained impetus after the epidemic of 1949, and before the vector was found the search had extended through many orders and families of insects. The search was culminated in 1953 with the incrimination of the eriophyid mite, Aceria tulipae (K.) by Slykhuis (39) as an important vector of the virus.

The mite, under ideal greenhouse conditions (41), was found to complete a life cycle in 8 to 10 days. Each mite was also found to produce a minimum of 12 eggs. Utilizing these figures, it is easy to calculate that each mite could produce a minimum of it or over 3 million individuals in a period of 60 days under ideal conditions. However not all of these individuals would survive nor would they all be viruliferous. However, these calculations clearly indicate a rapid buildup of mites could occur in the field under favorable conditions with the introduction of relatively few mites. Workers (8, 36) have been able to determine that the virus is not carried by the eggs of the mites but must apparently be obtained by the mites in the nymphal stages.

Staples and Allington (41) reported that windbreaks and deep vales did not interfere with the spread of the mite, indicating that topography had little effect on mite movement by the wind. Under these conditions, topography apparently had little effect but the Flint hills of Kansas (up to 75 miles wide), with isolated wheat and barley fields, seems to serve as an effective barrier in reducing the mite populations east of the Flint hills. Wheat streak mosaic virus has not been reported in the southeastern counties and mite populations have been consistently low.

Slykhuis (36), as was mentioned earlier, reported on the winter survival of mites. His findings indicated that extremely low temperatures may reduce mite populations but mites and their eggs apparently can survive the temperatures at which Yogo wheat is winter killed. Apparently mites are able to withstand more extreme temperatures than wheat, so extreme cold temperatures, while they may reduce populations slightly, cannot eliminate the vector of the disease. Del Rosario (9) found that adult mites could survive near freezing temperatures for a minimum of 3 months.

Slykhuis (36) also found that mites require a favorable microhumidity. Mites apparently could not survive a microhumidity of less than 100 percent at 25°C. for longer than 1 day. At this temperature, 40 percent of the eggs remained viable for a period of 3 days at a relative humidity of 75 percent. When the relative humidity was decreased to 50 percent, only 20 percent of the eggs remained viable for 1 day. From his results it becomes apparent that mite survival is drastically reduced under high temperatures and low relative humidities. During the summer months frequent small rains and cooler than average temperatures would tend to favor mite increase or survival while high temperatures coupled with below normal or infrequent heavy rains would tend to decrease the mite populations.

As wheat is normally harvested in Kansas in June and early July and the emergence of planted wheat does not occur until in the fall (September or later), the mites must have another host or hosts for survival. Very early volunteer wheat which grows under shattered maturing wheat after hail or lodging has been found to be the most favorable host for the mites (4). Some of the native grasses can support the mites for several days and other grasses can not only support them but also furnish an environment favorable for mite reproduction and colonization.

The utilization of the native grasses by the mites, although the relationship of the grasses to epidemiology has been questioned (41), provides them with a means of oversummering if no volunteer wheat is present, or at least provides the mites a temporary host until the appearance of volunteer wheat. Connin (5) was able to prove that some of the virus susceptible grasses provide "fair-good" or "good" hosts of the mites in terms of reproduction and colonization. Native grasses are probably of secondary importance to volunteer wheat but when volunteer wheat is absent, these grasses seem to become of primary importance in mite and virus survival.

# DELAYED PLANTING IN RELATION TO EPIDEMIOLOGY

## Review of Literature

Slykhuis (36) in 1955 placed pots of healthy wheat in the vicinity of a diseased spring wheat field at various times in the fall. He found a higher percentage of plants became infected in early September and the percentage of infected plants diminished with each week that passed. He suggested delayed planting in the areas where wheat streak mosaic was a threat.

Staples and Allington (41) planted wheat next to a severely diseased volunteer wheat field at weekly intervals. The percentage of diseased plants was correlated with the date of planting and they found that as time increased, the percentage of diseased plants decreased. They reasoned the decrease of infected plants was accounted for by the decreased exposure time in the fall of the later planted wheat to viruliferous mites.

Slykhuis et al (40) in 1957 planted wheat next to a diseased spring wheat field. Their results were much the same as those reported by Staples and Allington (41). They recommended seeding in early September in Alberta to minimize losses to wheat streak mosaic virus.

Gibson (13) was able to correlate not only the percentage of diseased plants with the date of planting but he was also able to correlate the percentage of plants infested with mites to the planting date.

## Materials and Methods

Figures were obtained from the Kansas State-Federal Crop Reporting Service in Topeka, Kansas which indicated when the Kansas wheat crop was from 83 to 90 percent planted. These dates, plotted on the axis, were compared with the known losses in Kansas due to the wheat streak mosaic virus. A correlation of loss with planting dates on a state wide basis was attempted.

## Experimental Results

As this is a fairly recent addition of the Crop Reporting Service, planting dates were obtained only for the years following 1951. The date by which the wheat crop was 83 to 90 percent planted varied considerably from year to year. It was found that the 1951 crop had been planted by September 23, 1950. This crop was reduced by $13,000,000 by the virus in this year, which is the earliest recorded date of seeding. The 1956 crop was planted by November 3, 1955, the latest recorded date of seeding, and only a trace of wheat streak mosaic was observed during this year. The intervening years had planting completed on various dates between these two extremes. During this period the disease loss varied from a trace to $14,000,000. The results are summarized in Plate XIV. The dates marked with a "T" denote a trace of mosaic. Dates marked with a "X" denote the various losses in dollars from the disease.

## EXPLANATION OF PLATE XIV

Fall planting dates from 1951-58 when the Kansas winter wheat crop was 83 to 90 percent planted compared with the known losses in dollars to wheat streak mosaic virus. T = Trace of mosaic.

PLATE XIV


14
10
5
Disease Loss in Dollars (000,000 omitted)
Sept. 20
25
30
Oct. 5
10
15
20
25
30
Nov. 4
Date Planting 83-90% Complete

After analyzing the data, it was felt that there is no apparent correlation on a state wide basis between the date of planting and the incidence of wheat streak mosaic virus. Local data in counties or portion of counties probably would show a direct correlation.

## Discussion

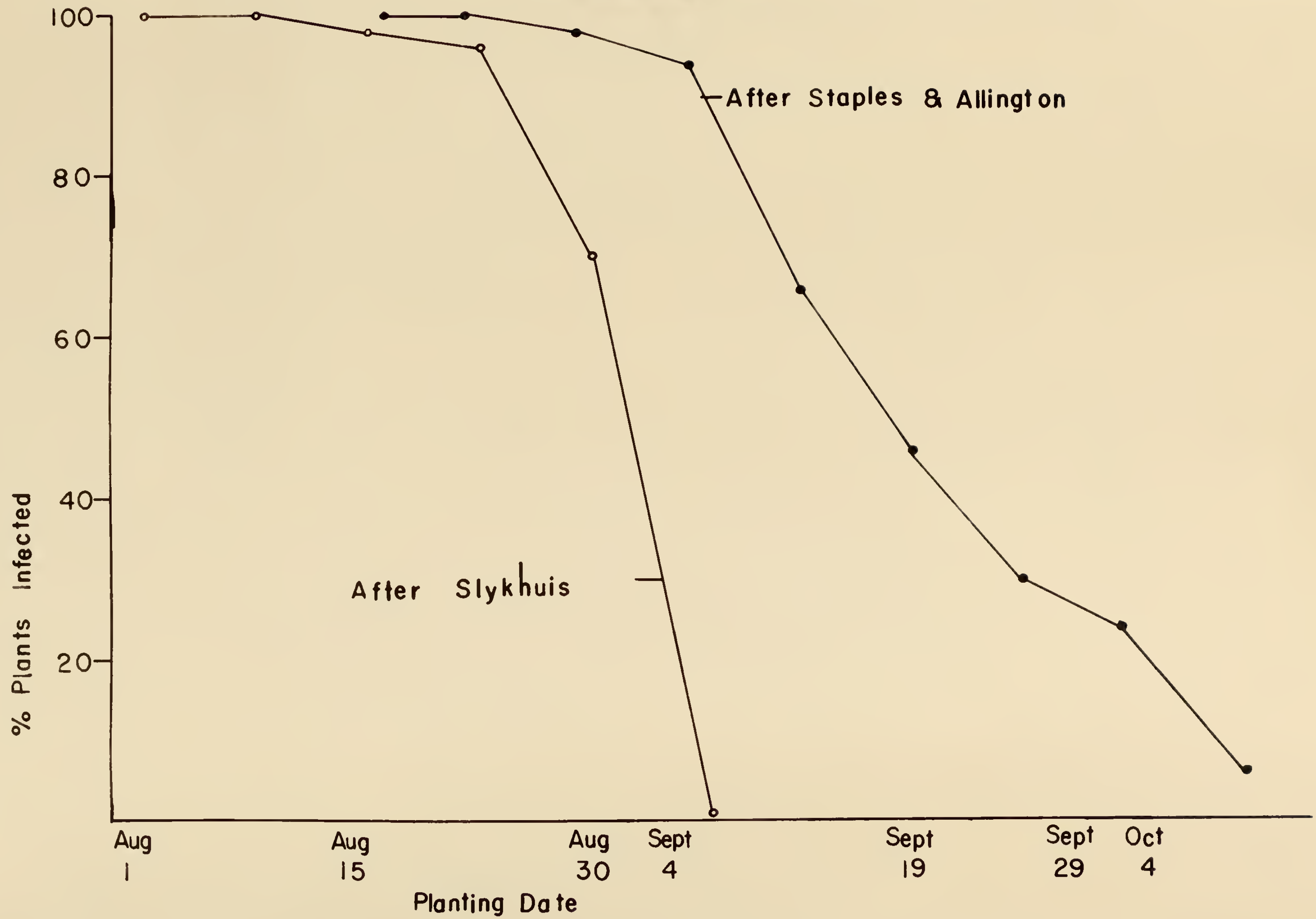
This study was made to see if there was a possible correlation between planting date on a state wide basis and the loss in dollars. If such a correlation could be found, it was felt that this possibly could serve as a means for predicting disease incidence for a given year.

Staples and Allington (41), Gibson (13) and Slykhuis et al (40) have reported that there is a definite correlation, on an individual field basis, between the percentage of diseased plants and the date of planting. Slykhuis et al (40) in Alberta, Canada found the percentage of diseased plants to decrease with each weeks delay in planting. Staples and Allington (41) in Nebraska found very similar results in their work. A slight difference between the two reports was noted and it is thought that the decrease in percentage of diseased plants in Nebraska is extended over a longer period of time because of the differences in temperatures where the observations were made. A composite graph was made of the two reports (Plate XV). These observations were made of plants in the vicinity of a severely diseased and mite infested field. This assured a ready supply

## EXPLANATION OF PLATE XV

The relationship of the date of planting to the percent of wheat plants infected with wheat streak mosaic virus. (Data of Slykhuist et al (40) and Staples and Allington (41)

PLATE XV


100
80
60
40
20
% Plants Infected
After Staples & Allington
After Slykhuis
Aug 1
Aug 15
Aug 30
Sept 4
Sept 19
Sept 29
Oct 4
Planting Date

of inoculum as well as an abundance of the mite vector.

On a state wide basis there is no apparent correlation between planting date and disease losses (Plate XIV). It was felt that if a correlation could be found it should prove to be similar to the correlations found by Slykhuis et al (40) and Staples and Allington (41) (Plate XV). The results of a comparison of the two methods points out the importance of delayed planting as a means of control. In this study of a state wide planting date, no assurance is made of a supply of inoculum nor of the mite vector. In a year when the disease is severe and there is a plentiful supply of inoculum along with an abundance of mites, early planting of wheat could spell destruction of a field. The evidence accumulated by others (40, 41) indicates that delaying the planting would decrease the percentage of infected plants. Dr. W. H. Sill, Jr. has observed (personal conversation) that a severely diseased field has never been found in Kansas planted after the first of October prior to the 1958-59 crop year. During this year he has observed one field severely diseased that was planted October 15, 1958.

This would certainly indicate that the wheat crop should not be planted before the first of October in Kansas to obtain maximum yields. Many Kansas farmers, however, plant wheat early to obtain maximum growth of the wheat plants so the field may be utilized as winter pasture. In an epidemic year the farmer must determine which is the most important, wheat or pasture. With an accurate prediction method and an efficient means of communication, the farmers of Kansas could be forewarned in epidemic years and planting could be delayed to reduce the incidence of the disease.

If planting is delayed to October 1 the incidence of the disease is normally reduced because of a two week delay before the wheat plants could possibly be large enough for inoculation by the mite vector to occur. In the present crop year the one observed diseased field planted on October 15 would have been inoculated about November 1 or later. The abundance of vectors this year (see Table 1 of the Appendix) and the warm November (2.4°F. above normal) were probably conducive to the late inoculation of this and probably other fields in the state.

## CLIMATIC FACTORS IN RELATION TO EPIDEMIOLOGY

### Review of Literature

Slykhuis (36), as was mentioned earlier, has found that the mites are able to withstand temperatures that "winter kill" wheat plants. He also found that at high temperatures and low humidities mites perished much sooner than at lower temperatures and higher humidities. He found that mite survival was "high" at 25°C. and 75 percent relative humidity for a period of 6 days after which it decreased until at 12 days no mites survived at this temperature and humidity. When he decreased the humidity to 75 percent at the same temperature (25°C.) he found that mite survival was "low" at the end of 1 day and at the end of 2 days no mites were able to survive.

Del Rosario (9) found that mites increased very rapidly at 75 ± 5°F. At 45 ± 5°F. she found mite increase to continue but to be slow. At 32 ± 5°F. there was no apparent mite increase.

The wheat crop, in order to be severely damaged, must be inoculated in the early fall (41). This indicates that the fall preceding harvest is of more importance in the spread of the virus than is the spring.

From these findings it was determined that there is apparently a 5 month period when weather factors can become critical for disease spread. These are the months from July through November of the year preceding harvest. The vector must survive the summer and have a favorable environment for fall inoculation if the disease is to be severe.

Staples and Allington (41) recorded both the temperature and rainfall departures from normal in their study of the hailed area of western Nebraska in the 1954 wheat crop. The hail occurred the previous summer (1953) and produced an excellent stand of volunteer wheat. Their results show that in July 1953 above normal rainfall occurred while August, September and October averaged slightly below normal. The temperatures for July and August averaged below normal but the months of September, October and November had average mean temperatures above normal.

Fellows and Sill (11) reported the counties of the state where wheat streak mosaic virus occurred during the 1952-53 and the 1953-54 seasons. These areas are shown in Plates XVI and XVII.

## Materials and Methods

Known disease loss records in Kansas were compared with official weather records to determine if a possible correlation between climatic factors and disease loss existed. Departures from normal of both temperature and rainfall were graphed and compared in the years from 1948 to 1959.

## Experimental Results

This study covered an 11 year period ending with the 1959 crop year. During this period the weather varied considerably, ranging from excessive moisture to drouth. The period studied is also marked by a great variance in disease loss.

The weather factors for the 5 month "critical" periods, as well as the disease losses are discussed below on an individual year basis.

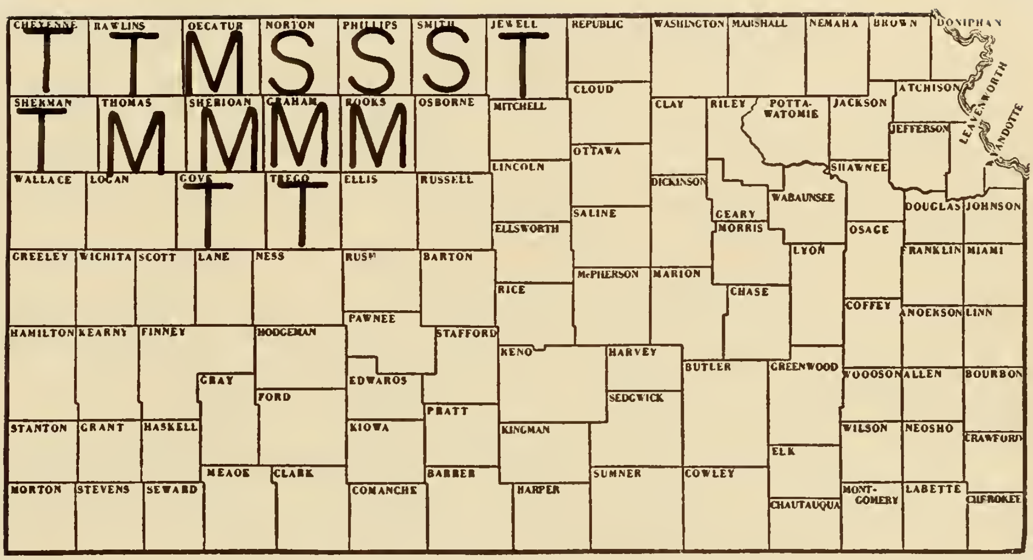
<u>1948-49 season</u>. This year was the first year in which a severe loss was recorded. Estimates after the harvest reported the loss to be $30,000,000 (28).

The mean temperatures of the summer and fall preceding harvest (Plate XVIII) indicates July averaged 1.3° below

## EXPLANATION OF PLATE XVI

Counties in Kansas where wheat streak mosaic occurred in the 1952-53 winter wheat crop.
T = trace of disease; M = moderate losses= S = severe losses. After Fellows and Sill (11).

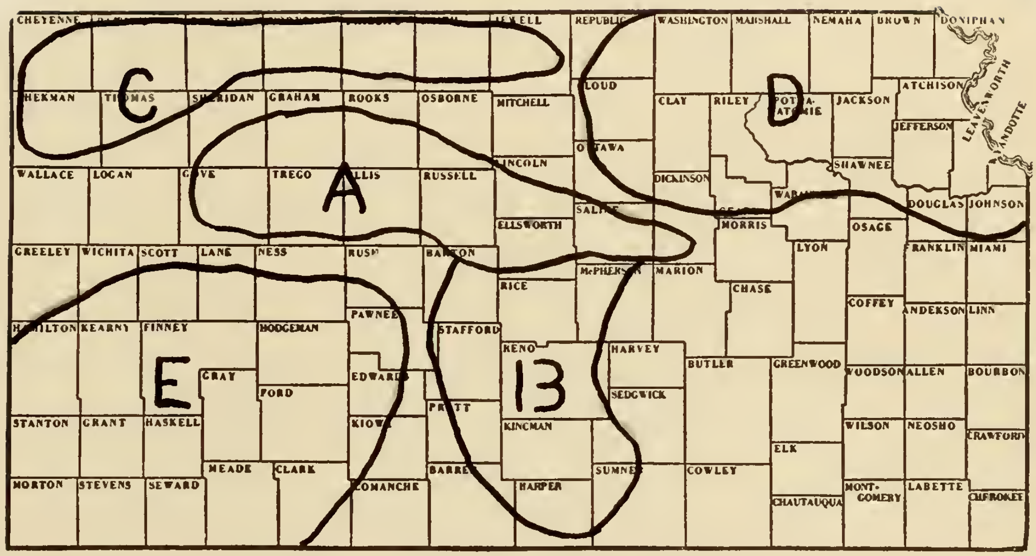
PLATE XVI


CHEYENNE
RAWLINS
DECATUR
NORTON
PHILLIPS
SMITH
JEWELL
REPUBLIC
WASHINGTON
MARSHALL
NEMAHA
BROWN
DONIPHAN
T
T
M
S
S
S
T
SHERMAN
THOMAS
SHERIDAN
GRAHAM
ROOKS
OSBORNE
MITCHELL
CLOUD
CLAY
RILEY
POTTAWATOMIE
JACKSON
ATCHISON
LEAVENWORTH
JEFFERSON
WYANDOTTE
T
M
M
M
M
WALLACE
LOGAN
GOVE
TREGO
ELLIS
RUSSELL
LINCOLN
OTTAWA
DICKINSON
GEARY
WABAUNSEE
SHAWNEE
DOUGLAS
JOHNSON
T
T
SALINE
ELLSWORTH
MORRIS
OSAGE
LYON
GREELEY
WICHITA
SCOTT
LANE
NESS
RUSH
BARTON
FRANKLIN
MIAMI
MCPHERSON
MARION
RICE
CHASE
COFFEY
ANDERSON
LINN
PAWNEE
HAMILTON
KEARNY
FINNEY
HODGEMAN
STAFFORD
RENO
HARVEY
BUTLER
GREENWOOD
WOODSON
ALLEN
BOURBON
GRAY
EDWARDS
FORD
SEDGWICK
PRATT
STANTON
GRANT
HASKELL
KIOWA
KINGMAN
WILSON
NEOSHO
CRAWFORD
ELK
MEADE
CLARK
BARBER
SUMNER
COWLEY
MORTON
STEVENS
SEWARD
COMANCHE
HARPER
CHAUTAUQUA
MONTGOMERY
LABETTE
CHEROKEE

EXPLANATION OF PLATE XVII

Approximate areas where wheat streak mosaic occurred in Kansas in the 1954 crop.
A and B = regions where losses were severe. C = region containing some smaller areas where losses were medium to severe. D and E = severe losses confined to scattered early planted fields, most fiels being healthy. After Fellows and Sill (11).

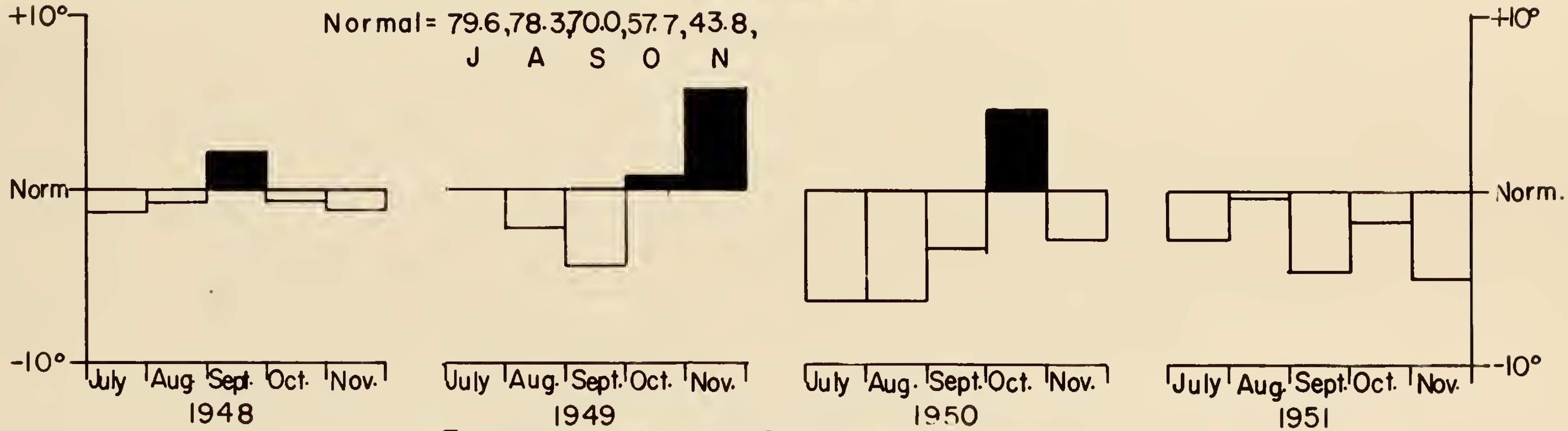
PLATE XVII


CHEYENNE
JEWELL
REPUBLIC
WASHINGTON
MARSHALL
NEMAHA
BROWN
DONIPHAN
C
D
SHERIDAN
GRAHAM
ROOKS
OSBORNE
MITCHELL
CLAY
RILEY
JACKSON
ATCHISON
JEFFERSON
LEAVENWORTH
WALLACE
LOGAN
TREGO
RUSSELL
A
DICKINSON
SHAWNEE
DOUGLAS
JOHNSON
ELLSWORTH
MORRIS
OSAGE
GREELEY
WICHITA
SCOTT
LANE
NESS
LYON
FRANKLIN
MIAMI
MARION
RICE
CHASE
COFFEY
PAWNEE
LINN
KEARNY
FINNEY
HODGEMAN
STAFFORD
HARVEY
BUTLER
GREENWOOD
ALLEN
BOURBON
E
GRAY
FORD
13
SEDGWICK
STANTON
GRANT
HASKELL
KINGMAN
WILSON
NEOSHO
ELK
MEADE
CLARK
COWLEY
MORTON
STEVENS
SEWARD
COMANCHE
HARPER
LABETTE
CHAUTAUQUA
MONT-GOMERY

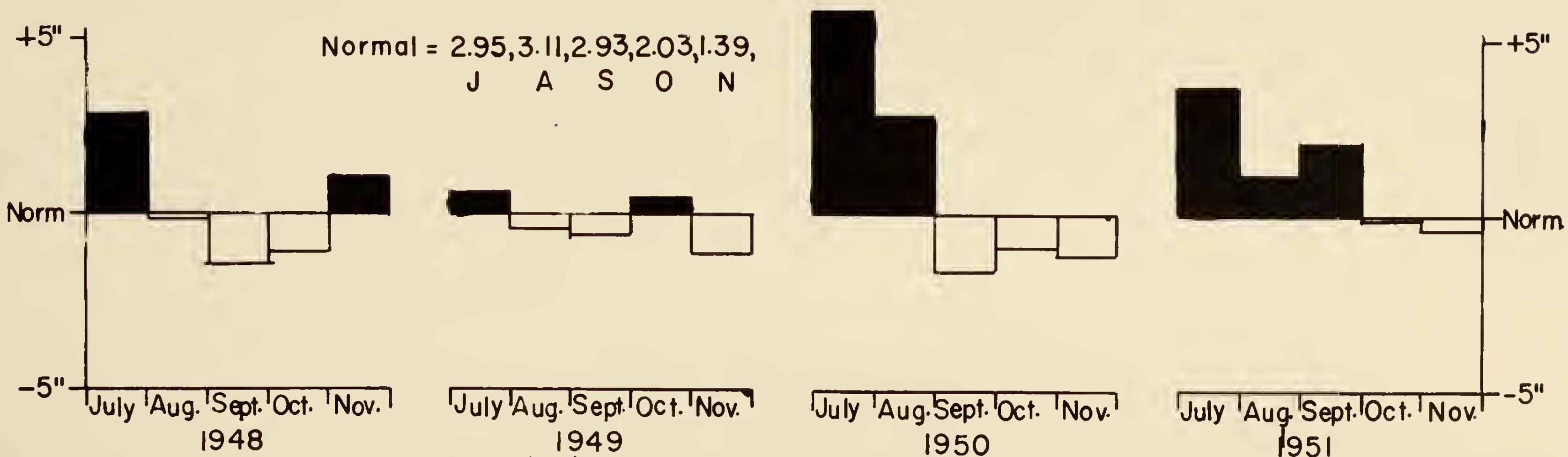
## EXPLANATION OF PLATE XVIII

State wide temperature and precipitation departures from normal during the "critical" periods for mosaic for the years 1948 through 1951.

## PLATE XVIII




Temperature Departures From Normal




Precipitation Departures From Normal

normal.[1] August was 0.7°F. below normal. September averaged 2.2°F. above normal, October was 0.6°F. below normal and November was 1.1°F. below normal. Rainfall for July was an excess of 2.94", while August (0.11"), September (1.41") and October (1.02") were below normal. November was 0.84" above normal.

<u>1949-50 season</u>. This year's "critical" period was characterized by normal July (79.6°F.) temperatures while August and September were 2.1°F. and 4.4°F. below normal. October and November were 0.8°F. and 5.8°F. above normal (Plate XVIII). Rainfall during this same period was 0.83" below normal.

The disease loss this year was recorded as a trace for the state of Kansas.

<u>1950-51 season</u>. This was also considered a severe year for losses from wheat streak mosaic virus. The loss estimate was reported to be $13,000,000 (32).

Both July and August (Plate XVIII) averaged 6.4°F. below normal while September averaged 3.4°F. below normal. October was 4.7°F. above normal and November was 2.9°F. below normal. Excessive rain fell in July (5.76" above normal) and August (2.77" above normal). The remaining 3 months of the "critical" period were 1.58", 0.86" and 1.19" below normal.

---

[1]Normal mean temperatures; July 79.6°, August 78.3°, September 70.0°, October 57.7° and November 43.8°F. Normal precipitation; July 2.95", August 3.11", September 2.93", October 2.03" and November 1.39".

1951-52 season. The rainfall (Plate XVIII) for this year was 3.65", 1.19" and 2.14" above normal for July, August and September. October and November were 0.06" and 0.37" below normal. The temperatures for this 5 month period were all below normal (2.8°, 0.4°, 4.6°, 1.8° and 5.0°F.).

It was reported that there was no loss in the state of Kansas during this year due to wheat streak mosaic (32).

1952-53 season. This year was an intermediate year with the loss reported to be $2,500,000 (52).

The mean temperatures for July (0.8°), August (1.3°) and September (1.0° were above normal. October (2.6°) and November (2.5°F.) were below normal. Rainfall for July was 0.68" below normal while August was 0.06" above normal. September and October show the beginning of the drouth being 2.32" and 2.01" below normal. November was slightly (0.32") above normal (Plate XIX).

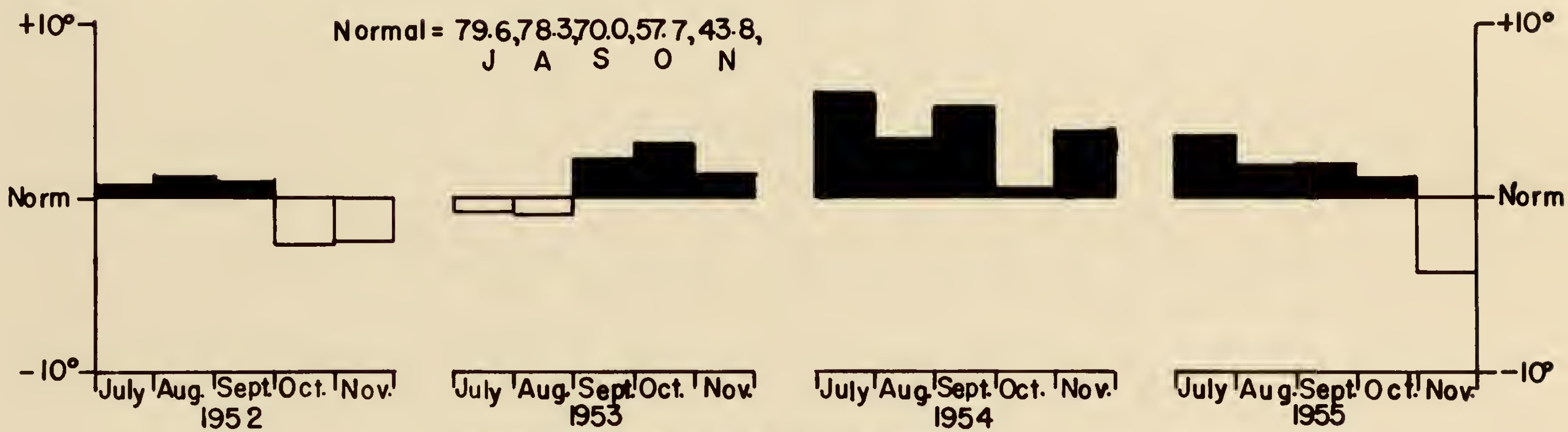
This season was analyzed further because of the known areas where the disease occurred (Plate XVI).

The Northwest division of the state contains 8 counties of which 1 had severe losses, 4 had moderate losses and 3 had a trace of the disease. The temperatures during the "critical" period for this division were; July 77.9°F. or normal, August 1.1° above normal or 77.0°, September 1.5° above normal or 68.8°, October 1.7° below normal or 53.0° and November 4.3° below normal or 36.3°F. Rainfall in this division was ± 0.40"

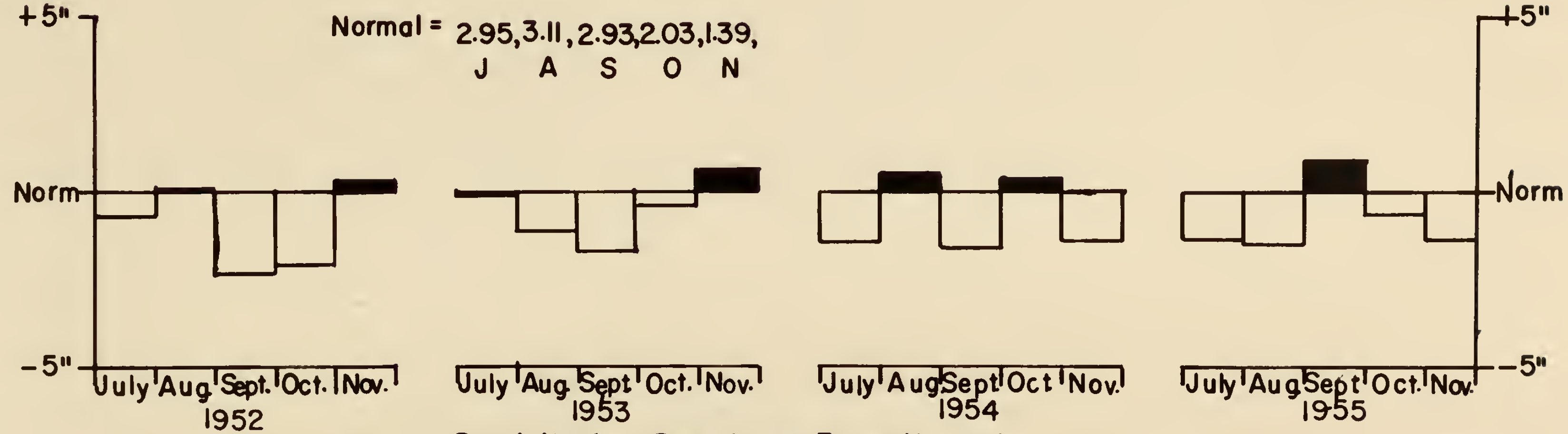
## EXPLANATION OF PLATE XIX

State wide temperature and precipitation departures from normal for the "critical" period of 1952 through 1955.

PLATE XIX




Temperature Departures From Normal




Precipitation Departures From Normal

from the normal July (2.73"), August (2.53") and November (0.70"). Normal rainfall and temperatures for this and the following individually discussed divisions are placed in parenthesis following the discussed month. September rainfall for this division was 1.41" below the normal rainfall of 1.83". October (1.12") was also dry being 1.03" below normal (Plate XX).

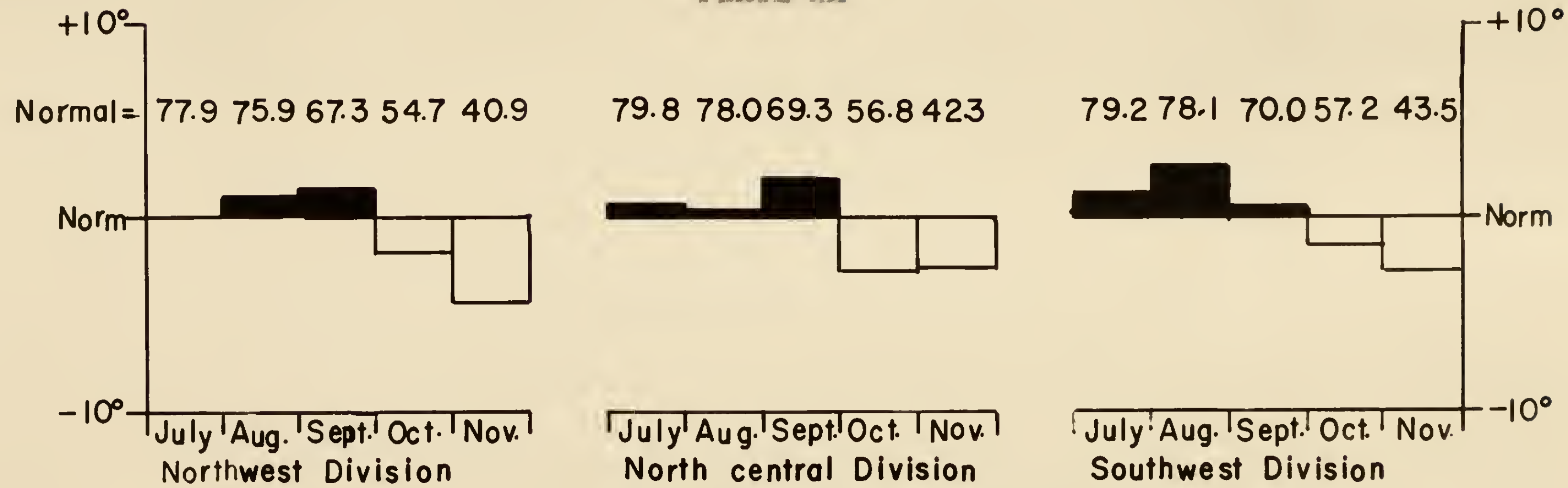
The North central division of the state contains 11 counties of which 2 had severe losses, 1 had moderate losses, 1 had a trace of the disease and the remaining 7 counties had no disease. The temperatures for the division indicate July (79.8°F.) was 0.7° above normal. August (78.0° was 0.4° above normal and September (69.3°) was 2.0° above normal. October (56.8°) and November (42.3°) were 2.8° and 2.6°F. below normal. Rainfall for July (2.93") was 2.01" below normal while August (3.22") was 0.15" above normal. September (2.76") was 2.00" below normal. October also was dry in this division having only a trace of rain instead of the normal 1.85". November (1.16") was 0.57" above normal (Plate XX).

The Southwest division, where no disease losses occurred, was chosen to compare the climatic factors of known disease areas with an area where no disease occurred. The temperature for July (79.2°F.) was 1.4° above normal and August was 2.7° above the normal 78.1°. September (70.0°) was exceeded by 0.6°, October (57.2°) and November (43.5°) were 1.5° and 2.7°F.

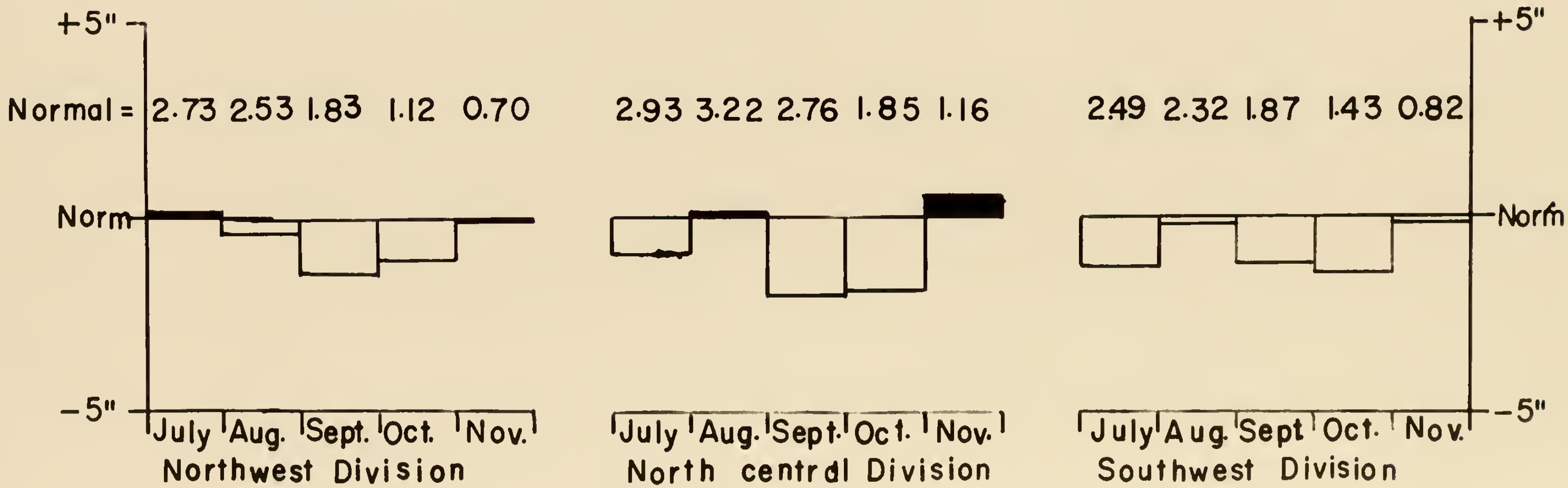
## EXPLANATION OF PLATE XX

Temperature and rainfall departures from normal for the "critical" period of the Northwest, North central, and Southwest divisions in 1952.

PLATE XX




Temperature Departures From Normal (1952)




Precipitation Departures From Normal (1952) below their normals respectively. This area of the state normally receives the least rainfall and during this "critical" period was below normal for all 5 months. July (2.49"), August (2.32"), September (1.87"), October (1.43") and November (0.82") were 1.24", 0.17", 1.73", 1.39", and 0.05" below normal respectively.

1953-54 season. During this season there was a loss of $14,000,000 (11, 32).

The mean temperature for July was 0.8°F. below normal. August was 1.0° below while September (2.2°), October (3.1°) and November (0.8°) were above normal. Rainfall was below normal for July (0.01"), August (1.08"), September (1.72") and October (0.32"). November was 0.67" above normal (Plate XVIII).

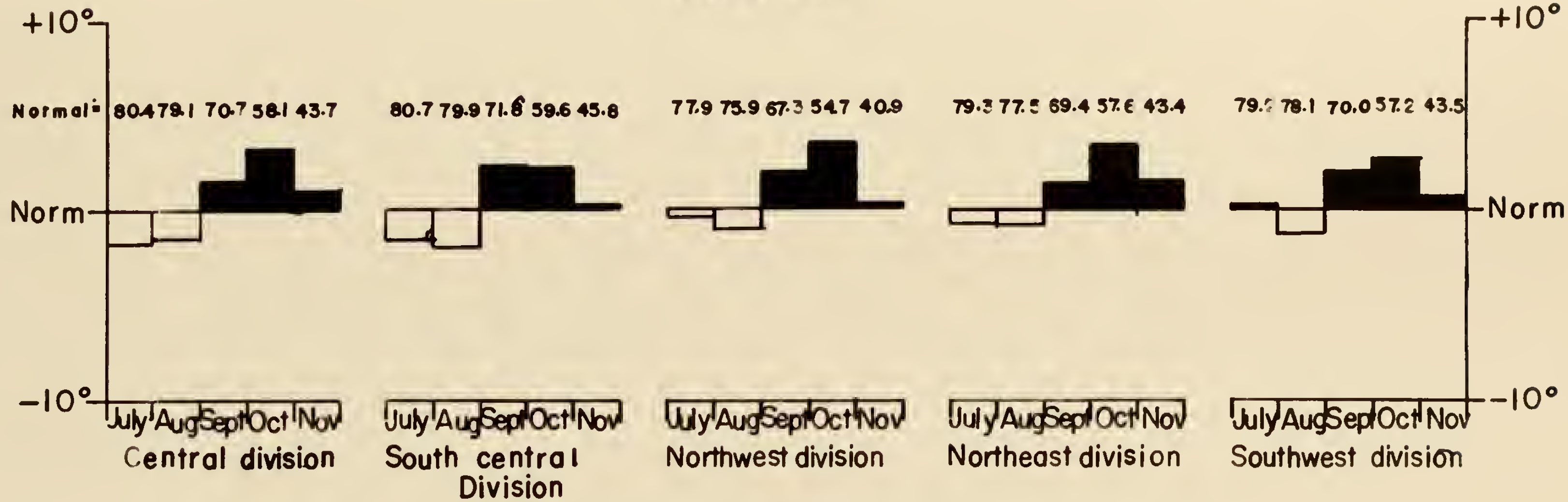
Fellows and Sill (11) through an extensive survey were able to outline the areas where losses were severe, where losses were medium to severe and where losses were confined to scattered early planted fields (Plate XVII). These areas correspond roughly to 5 of the 9 weather divisions of the state. These are the Central, South central, Northwest, Northeast, and Southwest divisions of the state. The departures from normal of both temperature and precipitation were graphed (Plate XXI).

The Central and South central divisions correspond to the areas where losses were severe. The Northwest area corresponds to the region containing some smaller areas where losses were medium to severe. In the Northeast and Southwest divisions

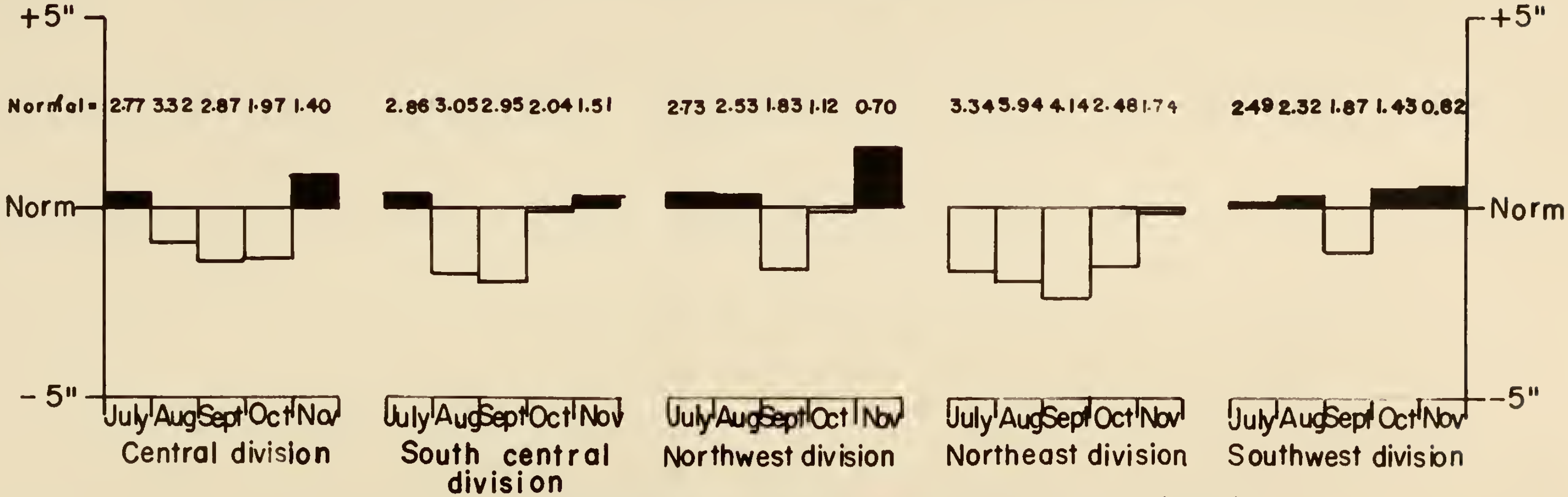
## EXPLANATION OF PLATE XXI

Temperature and precipitation departures from normal for the "critical" periods of the Central, South central, Northwest, Northeast and Southwest divisions of the state in 1953.

PLATE XXI




Temperature Departures From Normal (1953)




Precipitation Departures From Normal (1953) severe losses were confined to early planted fields with most fields being healthy.

1954-55 season. The loss this year was reported to be $250,000 (32) which can be considered as a trace of disease.

The rainfall was below normal for July (1.45"), September (1.51") and November (1.36"). The remaining months, August (0.53") and October (0.49"), were slightly above normal. The mean temperatures for this period were all above normal: July 6.0°, August 3.3°, September 5.2°, October 0.5° and November 3.7°F. (Plate XVIII).

1955-56 season. This year was characterized by below normal rainfall in July (1.30"), August (1.49"), October (0.57") and November (1.29"). September (0.88") was the lone month above normal for the "critical" period. Mean temperatures were above normal for July (3.5°F.), August 1.9°, September 2.0° and October 1.1°. November was 4.2°F. below normal (Plate XVIII).

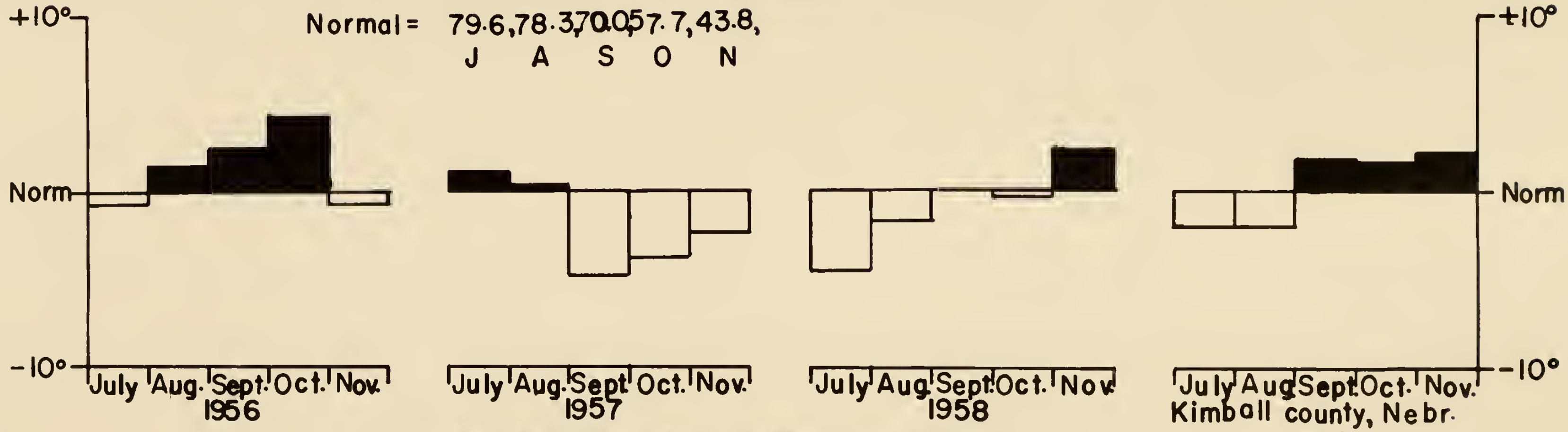
The disease loss for this year was reported as a trace.

1956-57 season. In this, the last of the drouth years, rainfall was slightly above normal (0.18") for July but the next four months, August (1.33"), September (2.35"), October (0.25") and November (0.31"), were below normal. Temperatures were recorded as 0.7° below normal in both July and November while August (1.5°), September (2.5°) and October (4.4°F.) were normal (Plate XXII).

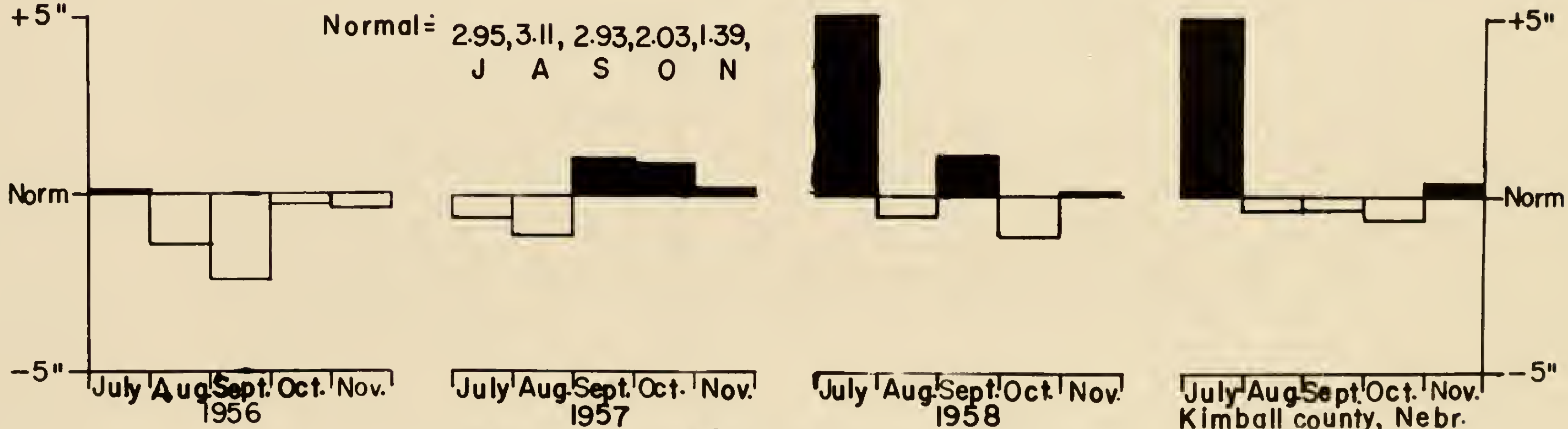
## EXPLANATION OF PLATE XXII

State temperature and precipitation departure from normal during the "critical" mosaic period of 1956, 1957 and 1958. Kimball County, Nebraska (1953) from Staples and Allington (41).

PLATE XXII




Temperature Departures From Normal




Precipitation Departures From Normal

This year was also reported as a year when only a trace of wheat streak mosaic occurred.

1957-58 season. In this year the drouth was broken although July (0.64") and August (1.14") were below normal in precipitation. September (1.06"), October (0.95") and November (0.25") were above normal. Mean temperatures for July (1.2°) and August (0.4°) were above normal. September (4.7°), October (3.8°) and November (2.4°F.) were below normal (Plate XXII).

The loss to wheat streak mosaic was reported as a trace.

1958-59 season. Although the disease loss for this season has not been completed, it appears to be the most severe year recorded. Loss estimates for this year range from 21,000,000 bushels (Newscast of WIBW-TV, June 10, 1959) to an estimate of from $50,000,000 to $80,000,000 by Mr. Claude King[1] as reported in the Kansas City Times, June 6, 1959.

Mean temperatures for July (4.5°F.), August 1.7°) and October (0.4°) were below normal. The September average was normal (70.0°) while November was 2.4° above normal. Rainfall for July was 5.02" above normal while September (1.21") and November (0.14") were also above normal. August (0.52") and October (1.16") were below normal (Plate XXII).

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[1]Extension Plant Pathologist, Kansas State University, Manhattan, Kansas.

## Discussion

It appears as though climatic factors may have an influence upon the vector as well as on the host. Slykhuis (36) proved that mites are able to withstand temperatures at which wheat is "winter killed".

Del Rosario (9) found that mites increased rapidly at 70 to 80°F. At 40 to 50°F. she found mite increase to continue but to be slower than at the higher temperature. At 27 to 37°F. there was no apparent mite increase.

The climatic pattern for severe years (1948-49, 1950-51, 1953-54 and 1958-59) indicates near normal rainfall during the "critical" period is necessary for a wheat crop to be severely damaged. It appears as though near and/or below normal July and August temperatures combined with above normal September, October and November temperatures increases the possibilities of a wheat crop becoming severely infected. This agrees with Del Rosario (9) in that at the higher (70 to 80°) temperatures mite reproduction is rapid and high populations of mites would be necessary for a severe epidemic to occur. It also agrees with Slykhuis (36) in that high humidities are necessary for mite survival at 25°C. (77.0°F.).

The discussion of each severe disease year is below.

<u>1948-49 season</u>. In this severe year, July and August (Plate XVIII) temperatures were below normal while September was above normal indicating 3 months during which the mean temperature

was maintained in the 70 to 80° range for rapid mite reproduction. October and November, while below normal, were warm enough to be placed in the intermediate temperature range where mite reproduction occurs but at a slower rate. Rainfall for July (2.94" above normal) was apparently sufficient for the development of host plants and the reproduotion of mites through the following three months which averaged 0.84" below normal.

1950-51 season. The July and August (Plate XVIII) temperatures were both 6.4°F. below normal. In September the temperature was also below normal but October was 4.7° above normal. These temperatures would have allowed a comparatively rapid rate of mite reproduction to occur assuring an abundance of the mite vector. Rainfall throughout the "critical" period was slightly (0.83") below normal but probably great enough in most areas to assure a rather favorable plant host situation.

1953-54 season. In this, a "dry" year, the July and August mean temperatures were below normal followed by above normal September, October and November temperatures (Plate XVIII). As the areas of the state where the disease occurred were outlined by Fellows and Sill (Plate XVII), this year was analyzed further. In Plate XX are the temperature and precipitation departures from normal for the 5 divisions of the state where the disease occurred. In the Central and South central divisions the losses were severe. In the Northwest were smaller areas where losses were medium to severe. The Northeast and Southwest divisions sustained severe losses to a few early planted fields with most fields being healthy (11).

A comparison of the different areas normal temperatures and precipitation supports the theory of cooler than normal summers combined with warmer than normal falls, with adequate moisture increasing the possibility of a severe wheat streak mosaic year.

The Central and South central divisions (most severely infected area, Plate XVII, had below normal July and August temperatures combined with the warm fall (Plate XX). Although precipitation was below normal during August and September, a minimum of 1" fell which apparently was enough through the "critical" period to allow host plants to grow and the mites to increase.

The Northwest division (smaller areas with medium to severe losses,(Plate XVII) appears upon a superficial examination to be an area that should have been severely diseased. There are several possible reasons for a reduced number of severely diseased fields. 1. The November mean temperature of this division approaches that where mite reproduction is stopped whereas the other divisions have November temperatures in which mite reproduction occurs but is slow. 2. The precipitation for September was 1.60" below normal, or only 0.23" of rain fell during this month. This probably caused a delayed emergence of most planted wheat which probably reduced the disease incidence in this area.

The Northeast division (Plate XVII), while it had the temperatures probably required for severe infection, suffered a shortage of moisture (Plate XX). All of the "critical" months were below normal and although this division has a high normal, apparently the prolonged period of much reduced moisture also reduced mite populations in this area as well as reducing the numbers of available host plants.

The Southwest division (Plate XVII) had relatively few scattered severely diseased early planted fields. Although temperatures were apparently favorable for severe infection, precipitation for the month of September was only 1.14" well below the normal 1.87", indicating conditions under which mite and host populations could have been reduced (Plate XX).

Included in Plate XXI is the temperature and precipitation departures from normal in Kimball County, Nebraska as reported by Staples and Allington (41). This was a severely diseased area of Nebraska during this season. Extensive areas of volunteer wheat had been produced by lodging and stuttering of wheat during a hail storm, providing an excellent oversummering host for both the mites and the virus. In general this area agrees with the severe areas in Kansas in regards to climatic factors. Below normal July and August temperatures with above normal September, October and November temperatures combined with adequate moisture for both mites and host plants. Apparently these factors created ideal circumstances for mite reproduction and volunteer wheat growth and, hence for severe losses.

1958-59 season. This season is apparently the most severe wheat streak mosaic year yet in Kansas. The July and August temperatures (Plate XXI) were below normal. September was normal, October near normal, and November was above normal. Precipitation for this season was adequate for not only good wheat growth but also favorable for mite reproduction.

1952-53 season. The 1952-53 season can be considered an intermediate year for wheat streak mosaic virus. During this year the loss was reported to be $2,500,000 (32). This season's diseased areas were also outlined by Fellows and Sill (11). It is believed that precipitation, although below normal in all three divisions where disease occurred (Plate XIX), was not a major factor because of the moisture available in the soil from the previous "wet" year. It was noticed, however, that the coolest July and August (Plate XIX) of the 3 divisions (Northwest) contained the largest number of counties where losses were experienced (Plate XVI). It was also observed that the other area (North central (Plate XVI) containing fields of diseased wheat, but with less counties involved, had warmer July and August (Plate XIX) temperatures than the more severed Northwest division. This area had cooler July and August temperatures than the Southwest division (Plate XIX) where no disease losses were reported.

The years studied which have not been mentioned are minor years for disease loss. Only a trace of wheat streak mosaic has been reported for these years (32). It appears in general

(Plates XVII, XVIII, and XXI) that the low incidence of disease in these years (1949-50, 1951-52, 1954-55, 1955-56, 1956-57 and 1957-58) is at least partially caused by any or all of the following reasons: 1. Below normal September mean temperatures which inhibit mite reproduction (1949-50, 1951-52 and 1957-58), 2. Above normal July and August temperatures, thus reducing the mites ability to survive (1954-55, 1955-56 and 1956-57) along with the below normal precipitation during this same period which evidently reduced the microhumidity and the presence of host plants.

As a generalized prediction statement, it appears that in Kansas, severe losses caused by the wheat streak mosaic virus are dependent upon cooler than normal summer (July and August), temperatures above normal in the fall (September, October and November), temperatures combined with adequate moisture for maintaining the high (100 percent) relative humidities required for mite survival as well as for rapid mite reproduction to take place.

## SUMMARY

Native grasses were tested by the author for susceptibility to the wheat streak mosaic virus. It was found that 21 species of native grasses from 33 seed sources were apparently immune to the virus. Two new symptomless carriers were found: *Sporobolus airoides* and *S. cryptandrus*. One new susceptible grass showing symptoms was also found, *S. neglectus*. *Sitanion* *hystrix* was also found to be susceptible in these experiments confirming the report of its susceptibility by Sill and Connin (34).

Grasses found which occurred naturally infected include: *Aegilops cylindrica* (Jointed goatgrass), *Bromus tectorum* (Downy chess), *Panicum capillare* (Ticklegrass), *Setaria viridis* (Green foxtail) and *Avena sativa* var. MO.-0-205 (Cultivated oats). The finding of these plants confirms the reports of McKinney, Slykhuis, Sill and Fellows as reported by Sill and Connin (34).

The susceptible grasses have been classified as being of major, questionable or minor importance in their roles as hosts of either mites, or virus or both. It was determined from the following criteria to which class a grass belonged: (a) Is the grass susceptible to the virus? (b) Are mites able to reproduce on this grass? (c) Is the grass found naturally infected in the field? (d) What is the habit of the plant? (e) In how many Kansas counties has the grass been collected? (f) What is the relative abundance of the grass in these counties? When volunteer wheat is sparce or absent these grasses can assume roles of major importance in the perpetuation of as well as the spread of the virus. However, volunteer wheat, when present, appears to be of more importance in the spread of the virus in epidemic proportions than are the native grasses.

The reproduction potential of the mite vector is tremendous. In a favorable environment it completes a life cycle in 8 to 10 days and each mite lays a minimum of 12 eggs (41). From these figures it was calculated that each mite could have $12^6$ or over 3 million descendents in 60 days under ideal conditions. Not all of these mites would survive nor would they all be viruliferous but the reproduction potential figures indicate that a rapid buildup of mite populations could occur in a relatively short period of time.

It has been previously shown (40, 41) that delaying the fall planting date in the vicinity of diseased volunteer wheat or spring planted wheat fields reduced the incidence of the disease. Based upon known planting dates in Kansas, this correlation could not be proven on a state wide basis in this study, but very probably is true under local conditions.

Climatic factors influence not only the growth of wheat and other host plants but also the population potential of mites. In this study it was determined that there is a "critical" period of 5 months when climatic factors are important for a severe mosaic year. Apparently three conditions which favor both host plant growth and mite development and are necessary for a severe mosaic year are: (a) Below normal July and August temperatures, (b) above normal temperatures for the remaining 3 months of the "critical" period and (c) adequate moisture for plant growth and to maintain a high microhumidity for the mites.

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# APPENDIX

Table 1. Summary of annual *A. tulipae* mite surveys. Coordinated by Mr. H. W. Somsen, U.S.D.A., A.R.S., Entomology Research Division, Kansas State University, Manhattan, Kansas.

| | 1954 | | 1955 | | 1956 | | 1957 | | 1958 | | 1959 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring | Fall | Spring | Fall | Spring | Fall | Spring | Fall | Spring | Fall | Spring |
| Number of counties surveyed[1] | 93 | 65 | 75 | 80 | 79 | 77 | 102 | 102 | 90 | 97 | 78 |
| Percent of counties with mite colonies[2] | 75 | 56 | 46 | 34 | 30 | 23 | 14 | 35 | 32[4] | 57 | 100[5] |
| Percent of counties with occasional mites[3] | 11 | 11 | 13 | 9 | 10 | 0 | 5 | 9 | 0 | 14 | 0 |
| Total percent of counties infested | 86 | 67 | 59 | 43 | 40 | 23 | 19 | 44 | 32 | 71 | 100 |
| Disease loss in Dollars (000,000 omitted) | $14, | | T[6] | | T | | T | | T | | T[7] |

Key
1 105 counties in state
2 groups of 6 or more mites per plant
3 5 or less mites per plant
4 found in volunteer, not in planted wheat
5 all counties surveyed had colonies but heaviest infestation in central 1/3 of state
6 trace of disease in Kansas
7 minimum estimate at time of writing is $42,000,000.

Table 2. The following crop plants produced reactions as indicated, when inoculated with wheat streak-mosaic virus. After Sill and Connin (34).

| Crop | Reaction | Authority |
|---|---|---|
| Wheats | A | McKinney, Sando, Slykhuis |
| Barley | B | McKinney, Slykhuis, Sill |
| Rye | B | McKinney, Slykhuis, Sill |
| Oats | B | McKinney, Slykhuis |
| Corn | C | McKinney, Fellows, Sill |
| Italian Millet | D | Slykhuis |
| Sorghum | E | Slykhuis, Fellows, Sill |
| Sugarcane | F | McKinney |

Key to reactions
- A. Susceptible
- B. Most- symptomless. Few- mild symptoms. Some- symptomless carriers.
- C. Few- susceptible. Many- symptomless or immune
- D. Symptomless or immune
- E. All tested- immune
- F. Local chlorotic lesions

Table 3. Annual grasses as susceptible to the wheat streak-mosaic virus. After Sill and Connin (34)

| Scientific Name | Common Name | Authority |
|---|---|---|
| Aegilops cylindrica | Jointed goatgrass | McKinney, Fellows |
| A. triuncialis | Barb goatgrass | McKinney, Fellows |
| Bromus japonicus | Japanese chess | McKinney, Fellows |
| B. secalinus | Cheat | Slykhuis |
| B. tectorum | Downy chess | Slykhuis, Sill |
| Digitaria ischaemum | Smooth crabgrass | McKinney, Fellows |
| Echinochloa crusgalli | Barnyard grass | Slykhuis, Connin |
| Eragrostis cilianensis | Stink grass | Slykhuis |
| Hordeum sp. | Yurasaki mochi | McKinney, Fellows |
| H. gussonianum | Mediterranean Barley | McKinney, Fellows |
| Panicum capillare | Tickle grass | Slykhuis, Connin |
| Setaria verticillata | Bur bristle grass | Slykhuis |
| S. viridis | Green foxtail | Fellows, Sill |
| Cenchrus pauciflorus | Sandbur-Symptomless carrier | Connin |

Table 4. The perennial grasses reported to be susceptible to the wheat streak-mosaic virus are as follows. After Sill and Connin (34).

| Scientific Name | Common Name | Reaction | Authority |
|---|---|---|---|
| _Bouteloua hirsuta_ | Hairy grama | C | McKinney |
| _Elymus canadensis_ | Canada wild rye | LCM | McKinney |
| _E. condensatus_ | Giant wild rye | LP | McKinney |
| _E. virginicus_ | Virginia wild rye | M | McKinney |
| _Eragrostis trichodes_ | Sand lovegrass | M | McKinney |
| _Oryzopsis hymenoides_ | Indian ricegrass | CP | McKinney |
| _Poa bulbosa_ | Bulbous bluegrass | LM | McKinney |
| _P. compressa_ | Canadian bluegrass | MP | McKinney |
| _Stipa robusta_ | Sleepy grass | M | McKinney |

Key to reactions
- L. Local lesions
- C. Symptomless or symptomless carrier
- M. Mosaic symptoms
- P. Only part of population showing symptoms

Table 5. Grasses reported to be naturally infected in the field with the wheat streak-mosaic virus. After Sill and Connin (34).

| Scientific Name | Common Name | Authority |
|---|---|---|
| _Aegilops cylindrica_ | Jointed goatgrass | McKinney |
| _Bromus japonicus_ | Japanese chess | McKinney |
| _B. tectorum_ | Downy chess | Slykuis |
| _Cenchrus pauciflorus_ | Sand bur | Sill |
| _Echinochloa crusgalli_ | Barnyard grass | Slykhuis |
| _Eragrostis cilianensis_ | Stinkgrass | Slykhuis |
| _Panicum capillare_ | Ticklegrass | Sill |
| _P. dichotomiflorum_ | Fall panicum | Sill |
| _Setaria viridis_ | Green foxtail | Fellows |
| _Elymus virginicus_ | Virginia wild rye | McKinney |
| _Sitanion hystrix_ | Squirreltail | Sill |

Table 6. Grasses recorded as immune to the wheat streak-mosaic virus. After Sill and Connin (34).

| Scientific Name | Common Name | Authority |
|---|---|---|
| *Agropyron cristatum* | Crested wheatgrass | Slykhuis |
| *A. dasystachyum* | Thickspike wheatgrass | Slykhuis |
| *A. desertorum* | Desert wheatgrass | Slykhuis |
| *A. elongatum* | Tall wheatgrass | Slykhuis |
| *A. inerme* | Beardless wheatgrass | Slykhuis |
| *A. intermedium* | Intermediate wheatgrass | Slykhuis |
| *A. repens* | Quackgrass | Slykhuis |
| *A. smithii* | Western wheatgrass | Sill |
| *A. trachycaulum* | Slender wheatgrass | Slykhuis |
| *A. trichophorum* | Stiffhair wheatgrass | Slykhuis |
| *Andropogon gerhardi* | Big bluestem | Connin |
| *A. scoparius* | Little bluestem | Connin |
| *Bouteloua sp.* | Grama grass | Connin |
| *Bromus inermis* | Smooth brome | Slykhuis |
| *Festuca rubra* | Red fescue | Slykhuis |
| *Panicum virgatum* | Switchgrass | Connin |
| *Phalaris arundinaceae* | Reed canarygrass | Slykhuis |
| *Phleum pratense* | Timothy | Slykhuis |
| *Poa pretense* | Kentucky bluegrass | Slykhuis |
| *Sorghastrum nutans* | Indiangrass | Connin |
| *Sorghum halepense* | Johnsongrass | Connin |
| *Avena fatua* | Wild oats | Slykhuis |
| *Eleusine indica* | Goosegrass | Sill |
| *Hordeum jubatum* | Wild barley | Slykhuis |
| *Setaria lutescens* | Yellow foxtail | Slykhuis |

Table 7. Reaction of millets to inoculation with wheat streak-mosaic virus; 25 plants of each type inoculated in each of two trials. As reported by Sill and Agusiobo (33)

| Accession No. | Species | Source | Reaction[a] |
|---|---|---|---|
| FC 23895 | Setaria italica | Germany | MS |
| FC 23902 | Setaria italica | Hungary | C |
| PI 163300 | Panicum miliaceum | India-2 | I |
| PI 170588 | Panicum miliaceum | Turkey-10 | MStr |
| PI 173754 | Echinochloa crusgalli | Turkey-13 | I |
| PI 173803 | Setaria italica | Turkey-13 | MS |
| PI 177543 | Setaria italica | Turkey-17 | MS |
| PI 179037 | Setaria italica | Turkey-18 | StrS |
| PI 179388 | Panicum miliaceum | Turkey-19 | MSStr |
| PI 180304 | Setaria italica | India-20 | M |
| PI 180450 | Panicum miliaceum | India-20 | MSStr |
| PI 180484 | Panicum ramosum | India-20 | M |
| PI 183332 | Echinochloa crusgalli | India-22 | MSStr |
| PI 195753 | Panicum miliaceum | China-32 | I |
| FC 32034 | Pennisetum glaucum variety Star | United States | I |
| FC 32149 | Common | United States | I |
| FC 32138 | Texas 7 | United States | I |

[a]Key to reactions
C - Symptomless carrier
I - Probably Immune
M - Mosaic
S - Stunt
Str - Streak

Table 8. Reactions of corn varieties to inoculation with wheat streak mosaic virus as reported by Sill and Agusiobo (33).

| Variety or P.I. No. | Source of pedigree | Type | Reaction[a] |
|---|---|---|---|
| Country Gentleman | | Sweet | I |
| Dakota White | | Field | M |
| Falconer | | Field | M |
| Golden Giant | | Sweet | LL-M |
| Midland | | Field | M |
| Pride of Saline | | Field | M |
| DoublexDouble $F_2$ | ((K6 x K44)(R30 x Wh 205)) ((K55 x T x 4R3)(R17 x K64)) | Field | M |
| K 1639 | (WF9 x 38-11)(K148 x K150) | Field | I |
| K 1859 | (WF9 x N6)(K148 x K150) | Field | M |
| K 2234 | (K41 x K55)(K63 x K64) | Field | I |
| K 1830 | (K201 x 38-11)(K4 x CI.7) | Field | M |
| 162573 | Argentine-1 | Sweet | M |
| 162575 | Argentine-1 | Pop | M |
| 162702 | Argentine-2 | Flint | I |
| 162927 | Paraguay-2 | Flint | M |
| 162928 | Paraguay-2 | Flint | I |
| 163144 | India-2 | Flint | LL-M |
| 165036 | Turkey-5 | Pop | I |
| 165041 | Turkey-5 | Flint | I |
| 165457 | Mexico-5 | Dent | I |
| 166042 | India-6 | Dent | I |
| 167095 | Egypt-8 | Flint | I |
| 167388 | Turkey-7 | Flint | M |
| 167975 | Turkey-8 | Flint | I |
| 171904 | Turkey-11 | Rice Pop | M |
| 171917 | Turkey-11 | Pop | M |
| 172334 | Australia | Dent | I |
| 172595 | Turkey-12 | Dent | I |
| 173828 | Turkey-13 | Dent | I |
| 174414 | Turkey-13 | Rice Pop | I |
| 174990 | Burma | Flint | M |
| 175334 | India-14 | Flint | I |
| 175976 | Turkey-15 | Rice Pop | I |
| 176804 | Turkey-16 | Pop | I |
| 177107 | Turkey-16 | Sweet | I |

Table 8. (Cont.)

| Variety or P.I. No. | Source of pedigree | Type | Reaction[a] |
|---|---|---|---|
| 177115 | Turkey-16 | Dent | I |
| 177590 | Turkey-17 | Flint | I |
| 177596 | Turkey-17 | Pop | I |
| 177617 | Turkey-17 | Flint | I |
| 177618 | Turkey-17 | Flint | I |
| 177621 | Turkey-17 | Flint | I |
| 177624 | Turkey-17 | Pop | I |
| 179131 | Turkey-18 | Rice Pop | M |
| 179132 | Turkey-18 | Sweet | M |
| 179141 | Turkey-18 | Pop | I |
| 181834 | Syria-20 | Flint | I |
| 181839 | Lebanon-20 | Pop | I |
| 181840 | Lebanon-20 | Flint | I |
| 181988 | Yugoslavia-21 | Dent | I |
| 182323 | Turkey-21 | Rice Pop | I |
| 182324 | Turkey-21 | Rice Pop | I |
| 183752 | Turkey-22 | Sweet | I |
| 183787 | Turkey-22 | Pop | I |
| 184276 | Yugoslavia-23 | Flint | I |
| 185059 | Turkey-23 | Flint | I |
| 185851 | Czechoslovakia | Flint | M |
| 185853 | Czechoslovakia | Flint-dent | M |
| 186187 | Uruguay-24 | Flint | M |
| 186193 | Africa-24 | Flint | I |
| 186197 | Australia-24 | Dent | I |
| 186204 | Palestine-24 | Dent | I |
| 186208 | South-Africa-24 | Flint | I |
| 186211 | Peru-24 | Flint | I |
| 186222 | Argentina-24 | Flint | I |
| 186233 | Australia-24 | Dent | I |
| 190081 | Guatemala-27 | Flint | I |
| 192946 | China-30 | Dent | M |
| 193430 | Hungary-30 | Dent | I |
| 193434 | Rumania-30 | Flint | I |
| 193438 | Rumania-30 | Dent | I |

Table 8. (Concl.)

| Variety or P.I. No. | Source of pedigree | Type | Reaction[a] |
|---|---|---|---|
| 193652 | Ethiopia-30 | Flint | LL-M |
| 193656 | Ethiopia-30 | Dent | M |
| 193658 | Ethiopia-30 | Dent | I |
| 193903 | Ethiopia-30 | Flint | I |
| 194048 | Ethiopia-30 | Flint | I |
| 195116 | Ethiopia-31 | Flint | I |
| 195741 | Ethiopia-32 | Flint | I |
| 196129 | Ethiopia-32 | Flint | M |
| 196130 | India-32 | Flint | M |
| 197094 | India-32 | Flint | M |
| 197503 | Ethiopia-32 | Flint-dent | I |
| 198641 | Ohio-33 | Sweet | I |
| 198741 | Afghanistan-33 | Flint | I |
| 198896 | Argentina-33 | Flint | I |
| 200198 | France-34 | Flint | I |

[a]Key
I- Probably immune
M- Systemic mosaic
LL- Local lesions (in many cases such plants became systemically infected later)

Table 9. Grasses immune from wheat streak mosaic virus as reported by Sill and Agusiobo (33).

| Common Name | Scientific Name | Source or number |
|---|---|---|
| Tall oatgrass | *Arrhenatherum elatius* (L.) Beauv. | FC 29367 |
| Western wheatgrass* | *Agropyron smithii* Rydb. | From field |
| " " | | FC 2436 |
| " " | | FC 23849 |
| Meadow foxtail | *Alopecurus pratensis* L. | |
| Smooth brome* | *Bromus inermis* Leyss. | From field |
| " " | | FC 24678 |
| Orchard grass | *Dactylis glomerata* L. | From field |
| " " | | PI 189388 |
| " " | | PI 184040 |
| " " | | PI 174773 |
| " " | | PI 172879 |
| " " | | PI 170347 |
| " " | | FC 24474 |
| " " | | FC 24009 |
| Guinea grass | *Panicum maximum* Jacq. | |
| Switch grass* | *Panicum virgatum* L. | |
| Indiangrass | *Sorghastrum nutans* (L.) Nash. | |
| Pampasgrass | *Cortaderia selloana* Schult. | |
| Reed canarygrass* | *Phalaris arundinacea* L. | From field |
| " " | | KG 2121-51 |
| " " | | KG 2190-51 |
| None | *P. arundinacea* x *P. tuberosa* | 211:42 |
| None | *Andropogon ischaemum* Thumb. | |
| Turkeyfoot | *Andropogon hallii* Hack. | |
| None | *Andropogon sibiricus* Steud. | |
| None | *Sorghum versicolor* Anderss. | |
| None | *Sorghum almum*** | |
| Job's tears | *Coix lacryma-jobi* Tourn. | |
| Johnson grass* | *Sorghum halepense* (L.) Pers. | |
| Buffalograss | *Buchloe dactyloides* (Nutt.) Engelm. | |

* Grasses previously reported as immune (34, 38)
** As described by Parodi, L.R., 1943. Rev. of Arg. Agron. 10:361.

Table 10. Monocotyledonous plants probably immune from the wheat streak mosaic virus as reported by Sill and Agusiobo (33).

| Family | Common Name | Scientific Name |
|---|---|---|
| Typhaceae | Common cat-tail | *Typha latifolia* L. |
| Alismaceae | Giant arrowhead | *Sagittaria monte-vidensis* Cham. & Schlect. |
| Amaryllidaeeae | Amaryllis | *Amaryllis* sp. |
| Iridaceae | Walking iris | *Iris* sp. |
| | Fleur-de-lis | *Iris* sp. |
| | Louisiana Iris | *Iris* sp. |
| | Blackberry-lily | *Belamcanda chinensis* D.C. |
| | Crocus | *Crocus* sp. |
| | Gladiolus | *Gladiolus* sp. |
| Cyperaceae | Umbrella plant | *Cyperus alternifolius* L. |
| | Nutgrass or Chufa | *Cyperus esculentus* L. |
| Araceae | Philodendron | *Philodendron* sp. |
| Commelinaceae | Wandering Jew | *Zebrina pendula* Schnizl. |
| | Tradescantia | *Rhoeo discolor* Hance |
| Lilaceae | Madonna lily | *Lilium candidum* L. |
| | Lily-of-the-valley | *Convallaria majalis* L. |
| | Grape hyacinth | *Muscari aemeniacum* Leicht. |
| | Onion | *Allium cepa* L. |
| | Ornithogalum | *Ornithogalum* sp. |
| | Solomon's seal | *Polygonatum* sp. |
| | False Solomon's seal | *Smilacina* sp. |
| | Tulip | *Tulip* sp. |
| Agavaceae | Bowstring-hemp | *Sansevieria thyrsiflora* Thunb. |
| | Soap weed | *Yucca glauca* Nutt. |
| Orchidaceae | Lady-slipper | *Cypripedium* sp. |
| | Orchid | *Orchis* sp. |
| Musaceae | Banana | *Musa* sp. |
| Cannaceae | Canna | *Canna* sp. |
| | Hallii canna | *Canna* sp. |
| | Hungaria canna | *Canna* sp. |
| Marantaceae | | *Marantia bicolor* Ker. |

Table 11. Dicotyledonous species immune from the wheat streak mosaic virus as reported by Sill and Agusiobo (33).

| Family | Common Name | Scientific Name |
|---|---|---|
| Piperaceae | Peperomia | Peperomia sp. |
| Euphorbiaceae | Croton<br>Redbird-cactus | Codiaeum variegatum Blume<br>Pedilanthus tithymaloides Poit. |
| Crassulaceae | Bryophyllum | Kalanchoe sp. |
| Moraceae | Rubber plant | Ficus elastica Roxb. |

Table 12. Susceptibility of annual grasses to wheat streak mosaic as reported by Slykhuis (36).

| Scientific Name | Common Name | Manual Inoculation | Mite Inoculation |
|---|---|---|---|
| Avena fatua L. | Wild oats | M (F) | M (F) |
| Bromus japonicus Thunb. | Japanese chess | M (F) | M (F) |
| B. secalinus L. | Cheat | M | M (F) |
| B. tectorum L. | Downy brome | M (F) | M (F) |
| Digitaria sanguinalis (L.) Scop | Crabgrass | M (F) | M (F) |
| Echinochloa crusgalli (L.) Beauv. | Barnyard grass | M (F) | M |
| Eragrostis cilianensis (All) Lutati | Stinkgrass | M (F) | M |
| Panicum capillare L. | Ticklegrass | M (F) | M (F) |
| Setaria lutescens (Weigel) Hubb. | Yellow foxtail | O | O |
| Setaria verticillata (L.) Beauv. | Bristly foxtail | M (F) | M |
| Setaria viridis (L.) Beauv. | Green foxtail | M (F) | M |

Key to reactions.
M. Mosaic symptoms
(F.) Few plants showing symptoms
C. No symptoms
O. Immune

Table 13. Reaction of wild grasses to infestation by viruliferous wheat curl mites under greenhouse conditions as reported by Connin (5).

| Scientific Name | Common Name | Habit[a] | Increase of Mites | Disease Transmitted by Mites |
|---|---|---|---|---|
| <u>Aegilops</u> <u>cylindrica</u> Host. | Jointed goatgrass | A | Fair-good | Yes |
| <u>Agropyron</u> <u>elongatum</u> Beauv. | Tall wheatgrass | P | None | No[c] |
| <u>Agropyron</u> <u>smithii</u> Rydb. | Western wheatgrass | P | Poor-fair | No[c] |
| <u>Alopecurus</u> <u>pratensis</u> L. | Meadow foxtail | P | None | No |
| <u>Arrhenatherum</u> <u>elatius</u> L. | Tall oatgrass | P | Poor | No |
| <u>Beuteloua</u> <u>curtipendula</u> (Michx.) | Sideoats grama | P | None | No |
| <u>Beuteloua</u> <u>gracilis</u> (N.B.K.) | Blue grama | P | None | No |
| <u>Beuteloua</u> sp. (possibly hirsuta) | Grama | P | Good | Yes |
| <u>Bromus</u> <u>inermis</u> Leyss. | Smooth brome | P | Very poor | No[c] |
| <u>Bromus</u> <u>tectorum</u> L. | Downy chess | A | None | No |
| <u>Cenchrus</u> <u>pauciflorus</u> Benth. | Sandbur | A | Good | Yes |
| <u>Dactylis</u> <u>glomerata</u> L. | Orchard grass | P | None | No |
| <u>Digitaria</u> <u>ischaemum</u> (Schreb.) | Smooth crabgrass | A | Fair-good | Yes |
| <u>Digitaria</u> <u>sanguinalis</u> (L.) | Crabgrass | A | Very poor | Yes |
| <u>Eleusine</u> <u>indica</u> (L.) | Goosegrass | A | None | No[c] |
| <u>Elymus</u> <u>canadensis</u> L. | Canada wildrye | P | Fair | No |
| <u>Eragrostis</u> <u>cilianensis</u> (All.) | Lovegrass | A | Poor | Yes |
| <u>Euchlaena</u> <u>mexicana</u> Schrad. | Teesinte | A | Poor | No |
| <u>Panicum</u> <u>capillare</u> L. | Ticklegrass | A | None | Yes |
| <u>Panicum</u> <u>virgatum</u> L. | Switchgrass | P | None | No[c] |
| <u>Phalaris</u> <u>arundinacea</u> L. | Reed canary grass | P | None | No[c] |
| <u>Setaria</u> <u>viridis</u> (L.) | Green foxtail | A | Good | Yes |
| <u>Sorghastrum</u> <u>nutans</u> (L.) | Indian grass | P | None | No[c] |

Key
a A = Annual
P = Perennial
c Host reported immune to wheat streak mosaic virus by Sill and Connin 1953(34).

Table 14. Grasses tested apparently immune to the wheat streak mosaic virus

| Scientific Name | Common Name | Habit[1] | Source |
|---|---|---|---|
| Agrostis hiemalis (Walt ) | Winter bent | P | PI 234681 |
| *Bouteloua curtipendula Michx.) | Side oats grama | P | Nebr. 52 |
| * " " | " " " | P | KG-482-53 |
| *B. gracilis (H.B.K.) | Blue grama | P | Capitan Mts., New Mexico |
| * " " " | " " | P | Syn. 40, Woodward, Okla. |
| * " " " | " " | P | Syn. 20, Woodward, Okla. |
| * " " " | " " | P | Marfa, Texas |
| * " " " | " " | P | KG-2269-53 |
| * " " " | " " | P | Elm Creek, Nebr. |
| * " " " | " " | P | PI 234682 |
| *Buchloe dactyloides (Nutt.) | Buffalo grass | P | Field |
| * " " | " " | P | Nebr. 111K |
| Calamovilfa gigantea (Nutt.) | Giant reed grass | P | Fort Supply, Okla. |
| Chloris verticillata Nutt. | Windmillgrass | P | Woodward, Okla. |
| " " | " | P | Butler Co., Kans. |
| Eragrostis spectabilis (Pursh.) | Purple lovegrass | P | Woodward, Okla. |
| Eriochloa contracta Hitch.) | Prairie cupgrass | A | Riley Co., Kans. |
| " " | " " | A | Pottawatomie Co., Kans. |
| Festuca octoflora Walt. | Six weeks fescue | A | Geary Co., Kans. |
| *Hordeum jubatum L. | Foxtail barley | P | PI 243683 |
| * " " " | " " | P | Scottsbluff, Nebr. |
| H. pusillum Nutt. | Little barley | WA | Republic Co., Kans. |
| Koeleria cristata (L.) Pers. | Prairie junegrass | P | P-6230, Pullman, Washington |
| " " | " " | P | Jackson Hole, Wyo. |
| Muhlenbergia asperfolia (Nees and Mey.) | Alkali muhly | P | Jackson Hole, Wyo. |
| Paspalum stramineum Nash. | Sand paspalum | P | Fort Supply, Okla. |
| Setaria faberii Herrm. | | A | Pott. Co., Kans. |
| *S. lutescens (Weigel) Hubb. | Yellow Foxtail | A | Pott. Co., Kans. |
| S. macrostachya H.B.K. | Plains bristlegrass | P | Woodward, Okla. |
| Spartina pectinata Link. | Prairie cordgrass | P | Woodward, Okla. |

Table 14. (Concl.)

| Scientific Name | Common Name | Habit[1] | Source |
|---|---|---|---|
| Sporobolus asper (Michx.) | Dropseed | P | Woodward, Okla. |
| Stipa virdula Trin. | Green needlegrass | P | Nebr. 53337 |
| Tridens flavus (L.) (Hitchc.) | Purpletop | P | Falls City, Nebr. |

1
P Perennial
WA Winter annual
A Annual
* Confirmation of previous immunity reports (3, 5, 34, 36, 37, 41).

Table 15. Grasses tested which were symptomless carriers of the wheat streak mosaic virus.

| Scientific Name | Common Name | Habit | Source |
|---|---|---|---|
| *Sporobolus airoides (Torr.) | Alkali sacaton " | P | A 3808, Albuquerque, New Mexico |
| * " " | " " | P | Riley Co., Kans. |
| * " " | " " | P | Pottawat. Co., Kans. |
| * " " | " " | P | Mandan, N.D. |
| *S. cryptandrus (Torr.) | Sand dropseed | P | Quinlan, Ont. |
| *" " | " " | P | Riley Co., Kans. |
| *" " | " " | P | Cain, Wyo. |
| *" " | " " | P | Nebr. 53542 |

* First report of being a symptomless carrier.

Table 16. Grasses tested which developed systemic symptoms when inoculated with the wheat streak mosaic virus.

| Scientific Name | Common Name | Habit | Source |
|---|---|---|---|
| **Sitanion hystrix (Nutt) | Squirreltail | P | Colo. |
| ** " " | " | P | PI 232353, Utah |
| *Sporobolus neglectus | Dropseed | A | Geary Co., Kans. |

* First report of being susceptible
** Confirms report of Sill (34).

Table 17. Susceptibility of cultivated crop plants to wheat streak mosaic virus and Aceria tulipae (K.) After Slykhuis (36).

| Species | Variety | Virus Susceptibility[a] | Mite Susceptibility[b] |
|---|---|---|---|
| Avena sativa L. | Victory | M | 0 |
| Echinochloa crusgalli (L.) Beauv. | Japanese Millet | M | 1 |
| Hordeum vulgare L. | Trebi | M | 1 |
| | Vantage | M | 1 |
| | O.C.A. 21 | M | 1 |
| Medicago sativa L. | | 0 | 0 |
| Panicum miliaceum L. | Proso millet | M | 0 |
| Secale cereale L. (winter type) | Dakold | M | 1 |
| Setaria italica (L.) Beauv. | Hungarian millet | M | 1 |
| Sorghum vulgare Pers. | Westland | 0 | 2 |
| Triticum dicoccum Schrank | Vernal | M | 2 |
| Triticum durum Desf. | Mindum | M | 3 |
| Triticum timopheevi Zhukov. | | M | 2 |
| Triticum aestivum L. (spring types) | Lee | M | 3 |
| | Marquis | M | 3 |
| | Rescue | M | 3 |
| | Thatcher | M | 3 |
| Triticum aestivum L. (winter types) | Jones' Fife | M | 3 |
| | Karkov 22 M.C. | M | 3 |
| | Minter | M | 3 |
| | Pawnee | M | 3 |
| | Yogo | M | 3 |
| Zea mays L. | Northern Cross | 0 | 0 |
| | Golden Rush | 0 | 0 |
| | Golden Giant | M | 2 |
| | Others | I-M | ? |

[a] M. Mosaic
O. No Mosaic
I-M. Immune to Mosaic

[b] 0-3. Degrees of susceptibility, with 3 being most susceptible.

Table 18. Susceptible grasses which could be of major importance in the epidomiology of wheat streak mosaic virus. Table a composite of reports by: Sill and Connin (34), Gates (12) and Connin (6).

| Scientific Name | Common Name | Mite increases | Habit | Counties where Collected[z] | Relative abundance[x] |
|---|---|---|---|---|---|
| *_Aegilops cylindrica_ Host. | Jointed goatgrass | Fair-good | A | 23 | Abundant |
| _Beuteloua hirsuta_ Lag. | Hairy grama | Good | P | 71 | Abundant |
| *+_Conchrus pauciflorus_ Benth. | Sandbur | Good | A | 88 | Abundant |
| *_Elymus canadensis_ L. | Canada wildrye | Fair | P | 97 | Abundant |
| *_Setaria viridis_ (L.) | Green foxtail | Good | A | 93 | Abundant |

Key

- * Found naturally infected in the field
- \+ Symptomless carrier
- A Annual
- P Perennial
- z Supported by herbarium specimen
- x In counties where collected

Table 19. Susceptible grasses of questionable importance in the epidemiology of wheat streak mosaic virus. Table a composite of reports by: Sill and Connin (34), Gates (12) and Connin (6).

| Scientific Name | Common Name | Mite increase | Habit " | Counties where collected | Relative abundance |
|---|---|---|---|---|---|
| *Bromus japonicus Thunb. | Japanese chess | ? | A | 43 | Abundant |
| B. secalinus L. | Cheat | ? | A | 43 | Infrequent |
| *B. tectorum L. | Downy chess | None | A | 32 | Abundant |
| Digitaria sanguinalis (L.) | Crabgrass | Very poor | A | 77 | Abundant |
| *Echinochloa crusgalli (L.) Beauv. | Barnyard grass | ? | A | 55 | Intermediate |
| *Elymus virginicus L. | Virginia wildrye | ? | P | 70 | Intermediate |
| *Eragrostis cilianensis (All.) | Stinkgrass | Poor | A | 104 | Abundant |
| E. trichodes (Nutt.) | Sand lovegrass | ? | P | 31 | Infrequent |
| *Panicum capillare L. | Ticklegrass | None | A | 103 | Abundant |
| *P. dichotomiflorum Michx. | Fall panicum | ? | A | 72 | Infrequent |
| *Sitanion hysterix (Nutt.) | Squirreltail | ? | P | 29 | Infrequent |
| +Sporobolus airoides (Torr.) | Alkali sacaton | ? | P | 21 | Infrequent |
| +S. cryptandrus (Torr.) | Sand dropseed | ? | P | 81 | Abundant |
| S. neglectus Nash. | Dropseed | ? | A | 40 | Infrequent |

Key
- * Found naturally infected in the field
- + Symptomless carrier
- ? Unknown
- A Annual
- P Perennial

Table 20. Susceptible grasses of minor importance in the epidemiology of wheat streak mosaic virus. Table a composite of reports by: Sill and Connin (25), Gates (35) and Connin (11).

| Scientific Name | Common Name | Mite increase | Habit | Counties where collected | Relative abundance |
|---|---|---|---|---|---|
| Digitaria ischaemum (Schreb.) | Smooth crabgrass | Fair-good | A | 6 | Infrequent |
| Oryzopsis hymenoides (Roem and Schult.) | Indian ricegrass | ? | P | 5 | Infrequent |
| Poa bulbosa L. | Bulbous bluegrass | ? | P | 2 | Infrequent |
| P. compressa L. | Canadian bluegrass | ? | P | 12 | Infrequent |
| Setaria verticillata (L.) | Bur bristlegrass | ? | A | 4 | Infrequent |
| Stipa robusta Scribn. | Sleepygrass | ? | P | 1 | Infrequent |

Key
- ? Unknown
- A Annual
- P Perennial

Table 21. Insects tested by Harvey (18) as possible vectors of wheat streak mosaic virus.

| Order or Family | Species |
|---|---|
| Cicadellidae | Several+[1] |
| Cicadellidae | *Endria inimica* (Say)+ |
| Cicadellidae | *Macrosteles divisus* (Uhler) |
| Cicadellidae | *Nesosteles* sp. |
| Cicadellidae | *Psammotettix* sp. |
| Cicadellidae Agalliini | Several |
| Cicadellidae Hecalini | Undetermined |
| Cicadellidae | *Exitianus exitiosus* (Uhler) |
| Cicadellidae | *Deltocephalus* sp. |
| Cicadellidae | *Empoasca* sp. |
| Aphididae | Several |
| Aphididae | *Toxoptera graminum* (Rond.) |
| Aphididae | *Aphis maidis* Fitch |
| Aphididae | *Rhopalosiphum prunifoliae* (Fitch) |
| Aphididae | *Macrosiphum granarium* (Kirby) |
| Aphididae | *Rhopalosiphum subterraneum* Mason+ |
| Aphididae | *Hysteroneura setariae* (Thos.) |
| Aphididae | *Aphis gossypii* Glov. |
| Aphididae | *Macrosiphum pisi* (Kalt) |
| Miridae | *Halticus bracteatus* (Say) |
| Miridae | *Trigonotylus ruficornis* (Goffrey) |
| Miridae | *Lygus pratensis* (Say) |
| Pentatomidae | Undetermined |
| Lygaeidae | Undetermined |
| Aleyrodidae | *Trialeurodes vaporariorum* (Westwood) |
| Delphacidae | Several |
| Thripidae | Several |
| Thripidae | *Prosothrips cognatus* Hood |
| Collembola | Undetermined |
| Agromyzidae | *Agromyza coquilletti* Mall. |
| Chloropidae | *Meromyza americana* Fitch+ |
| Acrididae | Several |
| Noctuidae | *Chorizagrotis auxiliaris* (Grote) |
| Tenthredinidae | *Pachynematus* spp. |

[1] Not identified to Genera
+ Believed to be possible vectors

Table 22. Insects tested by Connin and Staples as possible vectors of wheat streak mosaic virus (7).

| Insects | Show transmission |
|---|---|
| Blissus leucopterus | No |
| Chaetocnema pulicaria | No |
| Commellus sp. | No |
| Cuerna gladiola | No |
| Empoasca sp. | No |
| Endria inimica | Yes |
| Macrosiphum dirhodum | No |
| Macrosiphum granarium | No |
| Macrosteles fascifrons | No |
| Melanoplus bivittatus | No |
| Melanoplus mexicanus | No |
| Meromyza americana | Yes |
| Phalacrus sp. | Yes |
| Rhopalosiphum fitchii | No |
| R. maidis | No |
| R. subterraneum | No |
| Thysanoptera | No |
| Trigonotylus ruficornis | No |
| Toxoptera graminum | No |

# THE EPIDEMIOLOGY OF WHEAT STREAK MOSAIC VIRUS

by

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AN ABSTRACT OF A THESIS

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Wheat streak mosaic virus is a constant threat to the wheat crop. In 1949 it caused a loss of $30,000,000 and has varied since from a trace to the estimated loss this current year of $42,000,000.

An attempt was made to inoculate native grasses by the sap-carborundum technic to test their susceptibility to the virus. A minimum of 50 plants were tested of each grass on each of two separate trials. It was found that 21 species of native grasses were apparently immune to the virus. Two new symptomless carriers were found; Sporobolus airoides (Torr.) One new susceptible grass which developed systemic symptoms was found, Sporobolus neglectus Nash. A previous report of the susceptibility of Sitanion hystrix (Nutt.) was confirmed.

Five grasses were found naturally infected in the field, confirming previous reports. These grasses are; Aegilops cylindrica Host., Bromus tectorum L., Panicum capillare L., Setaria viridis (L.) and Avena sativa var. MO.-0-205.

The susceptible native grasses were classified as being of major, questionable or minor importance in the spread of the virus on the basis of the following criteria; (1) Is the grass susceptible to the virus? (2) Are mites able to reproduce on these grasses? (3) Is the grass found naturally infected? (4) What is the habit of the plant? (5) In how many Kansas counties has the grass been collected? (6) What is the relative abundance of the grass in these counties? When volunteer wheat is sparce or absent these grasses appear to play a major role in not only the spread of the virus but also in the year to year perpetuation of the virus especially during adverse growing conditions.

Known state wide planting dates were compared with known losses from wheat streak mosaic virus. Previous reports show a definite correlation on a localized basis when winter wheat is planted in the vicinity of diseased volunteer or spring wheat fields. On a state wide basis this correlation could not be proven.

Climatic factors have an influence on not only the growth of planted wheat but also upon the development of mite populations. Temperature and precipitation departures from normal were compared with known disease losses. It was determined that there was a five month "critical" period when climatic factors could be of importance in the spread of the virus. These five months (from July through November) apparently must have the following characteristics for the development of a severe mosaic year; (1) Below normal July and August temperatures, (2) above normal temperatures for the remaining three months of the "critical" period and (3) adequate moisture to maintain high microhumidities during the "critical" period. These conditions are necessary for the development of the host plants as well as for the rapid buildup of mite populations necessary for a wheat crop to be severely damaged by the wheat streak mosaic virus.