# RB56-178 Streak Mosaic of Wheat in Nebraska and Its Control

R. Staples
*University of Nebraska-Lincoln*

W.B. Allington
*University of Nebraska-Lincoln*

**UNIVERSITY OF NEBRASKA COLLEGE OF AGRICULTURE**
**AGRICULTURAL EXPERIMENT STATION**

**W. V. LAMBERT, Director** **E. F. FROLIK, Associate Director**

*Research Bulletin 178*

# Streak Mosaic of Wheat in Nebraska and Its Control

R. STAPLES AND W. B. ALLINGTON

**LINCOLN, NEBRASKA**
**JANUARY, 1956**

**UNIVERSITY OF NEBRASKA COLLEGE OF AGRICULTURE**
**AGRICULTURAL EXPERIMENT STATION**

W. V. LAMBERT, Director E. F. FROLIK, Associate Director

*Research Bulletin 178*

# Streak Mosaic of Wheat in Nebraska and Its Control

R. STAPLES AND W. B. ALLINGTON

**LINCOLN, NEBRASKA**
**JANUARY, 1956**

## CONTENTS

# Streak Mosaic of Wheat in Nebraska and Its Control

R. Staples and W. B. Allington[1]

## INTRODUCTION

A mosaic of wheat was first observed in Nebraska by Peltier in 1922. According to Haskell and Wood (1923) Peltier found diseased plants in a large number of winter and spring wheat varieties at Lincoln and, in some instances, he successfully inoculated wheat and corn from the juice of infected plants. The temperatures under which Peltier maintained his inoculated plants are unknown and other criteria now employed to characterize the viruses were not utlized. It is probable however that he was working with what is now known as wheat streak mosaic virus.

Although McKinney (1937) has reported mosaic as recurring to a small extent each year near Lincoln, Nebraska, wheat streak mosaic was not recognized as the cause of extensive losses in the winter wheat growing areas of the state until 1949. The occurrence of the disease has been sporadic in different areas of Nebraska since 1948 with the greatest losses being sustained in the western parts, particularly in Kimball and Cheyenne Counties. In 1954, the Kimball County winter wheat crop was almost a total loss because of this disease.

Collections made throughout the state have yielded strains of this virus. They differ somewhat in the severity and type of symptoms produced on wheat and other susceptible hosts. No careful study has been made at this laboratory of the differences between these strains. They are not known at present to differ in any important characteristics such as mode of transmission, host range, etc. This bulletin deals with the composite of this group of viruses under the general name of wheat streak mosaic.

In some areas of the state, crown rots and root rots may be predominant during the last stages of wheat streak mosaic infection. This is particularly true in the drier areas of the western part of the state

---

[1] Assistant Entomologist and Plant Pathologist. The writers are indebted to Mr. C. Walters, formerly County Agent in Kimball County, Nebraska for valuable services in making disease surveys, locating desirable study sites and making mite trap collections. The writers are also indebted to Mr. Henryk Jedlinski and Mr. Lloyd Andersen, Research Assistants, for help in carrying out the more technical phases of the study.

where the basic cause of the trouble was diagnosed as a crown rot for some years previous to 1950. However, it was soon recognized that date of planting was of considerable importance in reducing the incidence of these various disorders in the wheat crop and therefore the recommendation to wheat producers was to avoid early dates of planting if possible. Why date of planting was important in the control of wheat streak mosaic was not known until the discovery by Slykhuis (1953) of the relationship of the eriophyid mite, *Aceria tulipae* (Keifer), to the spread of the virus. With the vector of wheat streak mosaic virus known, factors involved in the epidemiology of wheat streak mosaic could be investigated.

This bulletin reports the results of studies on the epidemiology of wheat streak mosaic under Nebraska conditions. Particular attention is given to the occurrence and certain characteristics of the mite vector of the virus, the relation of weather and other factors to some of its activities, a correlation of certain mite situations with epidemics of the disease, and recommendations for disease control.

## SYMPTOMS OF THE DISEASE

Symptoms are not reliable criteria for the identification of many virus diseases of plants and this is true of wheat streak mosaic. The symptoms vary with different situations. Among the factors affecting symptom expression are time of infection, temperature, soil moisture, soil fertility, the strain of the virus and the variety of the wheat. McKinney (1930) has described the symptoms expressed by wheat yellow-streak mosaic under standard conditions of light and temperature.

Observations in Nebraska wheat fields have seldom revealed recognizable symptoms of wheat streak mosaic in the fall. Occasionally, in years of abnormally high late fall temperatures and favorable conditions for early spread of the virus by the mite vector, typical symptoms have been observed as early as the first week in October. Commonly, however, symptoms are difficult to recognize until growth starts in the spring. With the occurrence of warm weather for brief periods in late March and early April, symptoms of the disease rapidly appear and continue to increase in severity as long as rapid growth lasts.

The first symptom is a faint green mottling of the expanding leaves. This is difficult to see except under properly adjusted light conditions. Then, the development of light colored streaks along the veins becomes evident and at this stage a general stunting of the plant can be detected. As the disease progresses, this chlorosis becomes more pronounced with the leaves of infected plants exhibiting yellowish-green to markedly yellow mottling and striping. At a distance, severely affected wheat may appear lighter in color than healthy winter wheat and without careful examination such diseased wheat may easily be

considered to be suffering from nitrogen deficiency. Infected plants tend to be less upright in growth habit than healthy plants. This is especially true in fields with poor stands. Severely infected plants may not produce heads. Less seriously affected plants may produce poorly filled heads often containing shriveled kernels.

In western Nebraska crown rots sometimes are prevalent in the spring in wheat afflicted with the last stages of wheat streak mosaic infection. Although it appears that such crown rots may sometimes be directly associated with wheat streak mosaic infection, this has not been demonstrated experimentally.

## BIOLOGY OF ACERIA TULIPAE (K.), VECTOR OF WHEAT MOSAIC VIRUS, AND EFFECTS OF THIS MITE ON WHEAT

Slykhuis (1953) incriminated *Aceria tulipae* (Keifer) as the vector of wheat streak mosaic virus and later (1955) presented evidence that this eriophyid species could transmit several "isolates" of wheat streak mosaic virus obtained from the United States and Canada. It appears probable that *A. tulipae* is an efficient vector of all isolates, strains, or varieties of the wheat streak mosaic virus. Moreover, Slykhuis (1955) also claims that *A. tulipae* can transmit a nonmanually transmitted factor which is probably virus in nature.

Keifer (1938) first described *A. tulipae,* giving the average measurements of the adult as 250 microns by 75 microns. These mites therefore, are rarely visible to the naked eye when occurring singly. At times, however, they reproduce in such numbers that they accumulate in masses and are then recognized on the leaf surfaces as a whitish granular substance sometimes giving the superficial observer the impression of mildew infection. As indicated by Slykhuis (1955) wheat plants heavily infested with *A. tulipae* may display various degrees of chlorosis and necrosis. The effects of mite infestation are particularly severe if the wheat plants are suffering from drought. Generally, however, such adverse effects are not apparent in winter wheat under field conditions.

Slykhuis (1955) presents concisely the life cycle of *A. tulipae,* stating that this species like many other eriophyids has two nymphal instars before becoming an adult. The shortest life cycle at 25°C. observed by Slykhuis was seven days from "egg to egg." No information is given on the average number of eggs produced.

The life cycle of *A. tulipae* has been determined by the present authors employing the following method:

1. A wheat seedling leaf was marked with a small spot of carmine stain on the upper surface and two small dots on the lower surface equally distant from the spot on the upper surface. The spots on the lower surface were approximately ¼ inch apart and served as guides for placing a clip on the folded leaf.

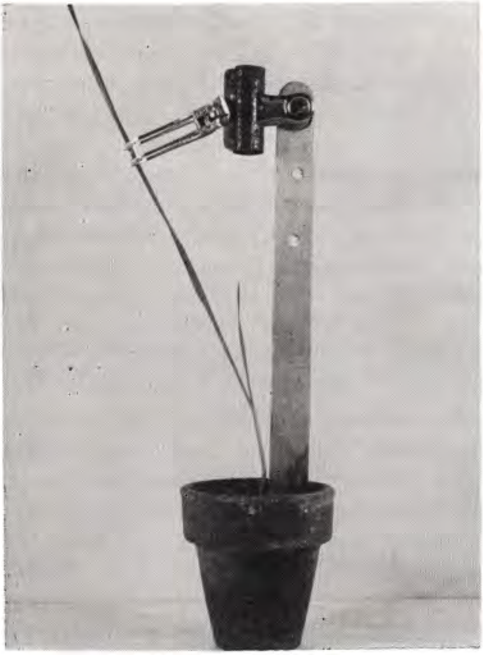
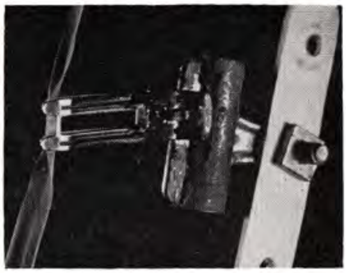



FIGURE 1.—Technique employed in confining *Aceria tulipae* (K.) to a delimited area of a wheat leaf. The folded leaf was held by prongs of a hair clip, as illustrated above.

2. An egg or mite was placed near the carmine-marked spot on the upper surface. The egg or mite was located by this spot when the leaf was examined later.

3. The leaf was then folded along the mid-vein so that the egg or mite was enclosed by the folded leaf.

4. A two-pronged hair clip was slipped over that portion of the folded leaf bearing either the mite or egg. The marks on the under surface of the leaf aided in centering the mite or egg on the upper leaf surface between the prongs of the clip. The clipped and folded leaf was held upright by another clip attached to a stick inserted in the soil in the pot (see figure 1). The wheat seedlings were grown in 2-inch pots to facilitate examination of mite bearing leaves under the dissecting microscope when the pots were placed on their sides. The temperature under which the life cycle of *A. tulipae* was studied was 75° to 78°F.

Examinations of the mite-bearing leaves were made twice daily, usually in the forenoon and again in the evening. The determination of the various details of the life cycle was sometimes very difficult. Many of the eggs and mites were crushed or the active stages disappeared because they were not held in strict confinement between the prongs of the clip. Although several hundred attempts were made to rear *A. tulipae* from egg to adult, success was obtained in but nine

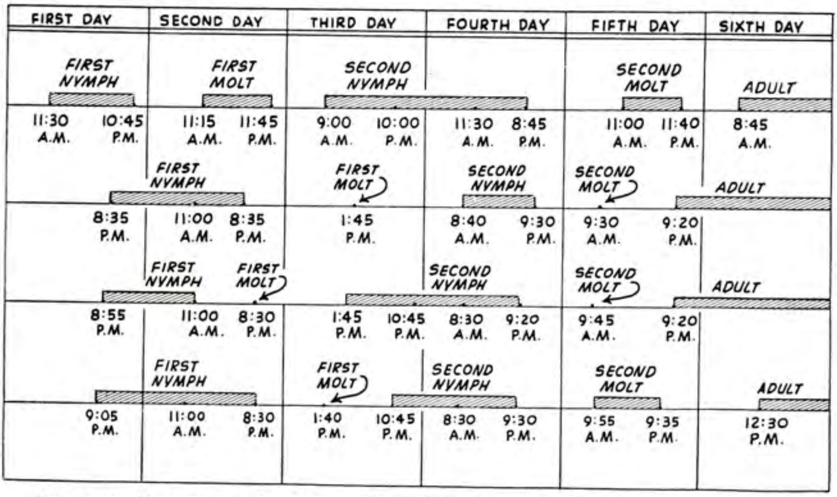


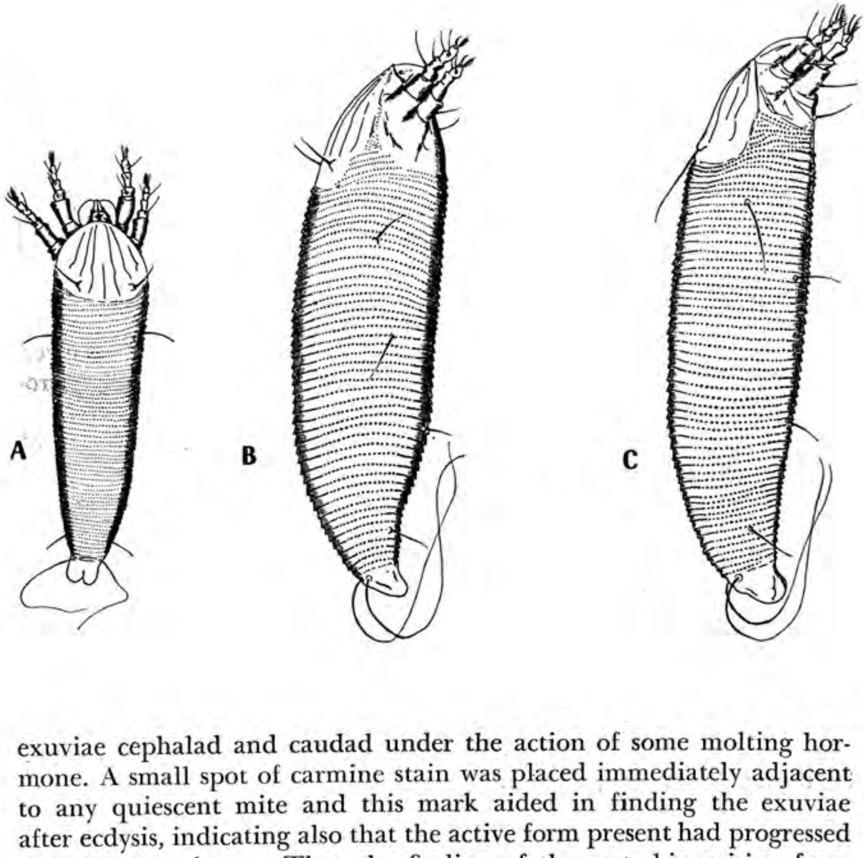

FIGURE 2.—Diagrammatic presentation of the life cycle of four specimens of *Aceria tulipae* (K.) determined by observations made twice daily.

instances. Specimens of the immature and molting forms were removed from the clipped leaves and cleared, stained and mounted for microscopic examination by a method detailed by Keifer (1952).

A diagrammatic presentation of the life cycle of four specimens of *A. tulipae* determined with two daily observations is illustrated in figure 2. The first nymphal instar was readily recognizable because of its minute size, its rather triangular shape immediately after emerging from the egg and its habit of remaining close to the chorion. The first and second molt forms were quiescent, incapable of movement when stimulated tactually and appeared translucent anteriorally and sometimes posteriorally (see figure 3). The anterior and posterior translucent regions apparently were caused by the molting mite shrinking in those areas away from the exuviae or by the distention of the

FIGURE 3.—Photomicrograph of molting stage of *Aceria tulipae* (K.) demonstrating the translucent anterior region.

FIGURE 4.—The various instars of *Aceria tulipae* (K.). A. Dorsal view of the first nymph soon after emerging from the egg. B. Lateral view of the first nymph immediately before the first ecdysis. C. Lateral view of the second nymph soon after the first ecdysis. D. Dorsal view of the second nymph immediately before the second ecdysis. E. Dorsal view of the adult soon after the second ecdysis. F. Lateral view of the adult some time after the second ecdysis. These figures are all drawn to the same scale and magnification is approximately 440 times.




exuviae cephalad and caudad under the action of some molting hormone. A small spot of carmine stain was placed immediately adjacent to any quiescent mite and this mark aided in finding the exuviae after ecdysis, indicating also that the active form present had progressed into the next instar. Thus the finding of the cast skin arising from the first molt demonstrated that the mite was in the second instar and in turn the exuviae of the second molt plus the fact that eggs were produced indicated that the adult stage had been reached. Owing to a marked similarity of morphological detail and an overlapping of size, adjacent instars could not be separated with any degree of surety without observing their development from the egg in the manner already described. Thus on visual examination the first instar of living mites could be confused with the second and the second in turn with the adult.

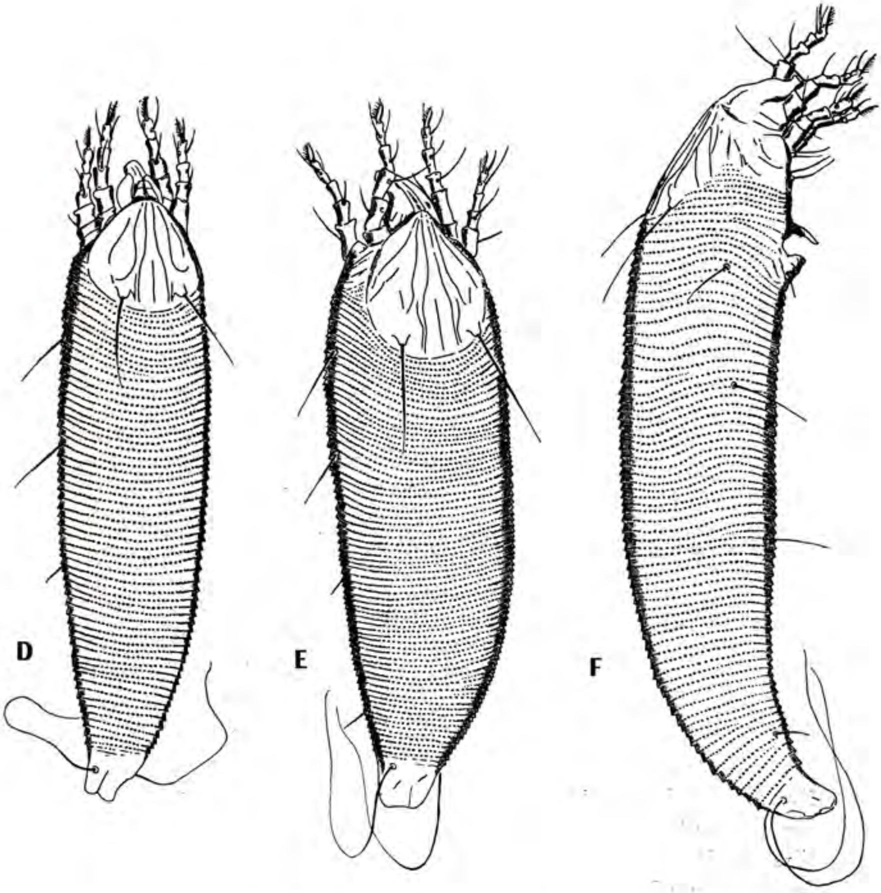



Figure 4 depicts the various instars of *A. tulipae*. These camera lucida drawings were made from specimens cleared and stained by a method formulated by Keifer (1952). Each figure is drawn to the same scale and the magnification is approximately 440 times that of the actual size of the specimens observed. The two views of each instar were selected to display the variance in size found in each instar. It is obvious that differences in size are not criteria by which the various instars may be separated. The shortest and longest specimens of 28 first nymphs measured were 98 microns and 170 microns respectively. Similarly, of 14 second nymphs, the smallest measured 163 microns in length and the largest 222 microns. The smallest adult of nine specimens measured was 176 microns long and the largest was 232 microns. Measurements of the widths of specimens of the various instars also overlapped from instar to instar. This overlapping is also apparent in

the measurements of the different instars presented by Slykhuis (1955).

Morphologically the various instars are remarkably similar. The setal arrangement is the same throughout all the forms with the exception of those setae located on the posterior margin of the shield of the first nymph. An examination of 30 specimens revealed that these dorsal shield setae, rather than projecting backward over the abdomen, either arise perpendicular to the body surface or project slightly cephalad. The dorsal setae of 15 second nymphs were similar to those of the adults and projected caudad.

An examination of figure 2 reveals that with discontinuous observations, the various growth stages may be determined but not the maximum lengths of times this mite species may spend in the various stages. Consequently, the longer time periods during which the different forms of *A. tulipae* were kept under observation in all attempts at rearing this species from egg to adult are presented in table 1. The figures in any horizontal line in this table were not obtained from a particular specimen of *A. tulipae* but from several specimens. It will be noted that the longest period the first nymph was observed was 35 hours, the first molt 15 hours, the second nymph 33 hours and the second molt 13 hours. The maximum time period the first nymph was observed closely approximates that for the second nymph and the time periods for the two molting forms are quite similar. Figure 2 shows that even these maximum time periods are probably too short. Since four to five days must elapse from hatching until the adult stage is reached, the following estimates are probably accurate within a few hours:

| | |
|---|---|
| Egg incubation period | 3 days |
| First nymph | 1½ days |
| First molt | ¾ day |
| Second nymph | 1½ days |
| Second molt | ¾ 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 |

TABLE 1.—The longer time periods during which various stages of *Aceria tulipae* (K.) were kept under observation on Cheyenne wheat at 75°-78° F.

| Hours first nymph observed | Hours first molt observed | Hours second nymph observed | Hours second molt observed | Hours preoviposition period observed | Days from first nymph to adult |
|---|---|---|---|---|---|
| 23 | 13 | 32 | 12 | 24 | 4 |
| 35 | 15 | 33 | 11 | 24 | 4 |
| 24 | 12 | 23 | 12 | 22 | 4 |
| 24 | 13 | 24 | 13 | 48 | 4½ |
| 26 | .... | 23 | .... | 34 | 4 |
| 23 | .... | .... | .... | .... | 5 |

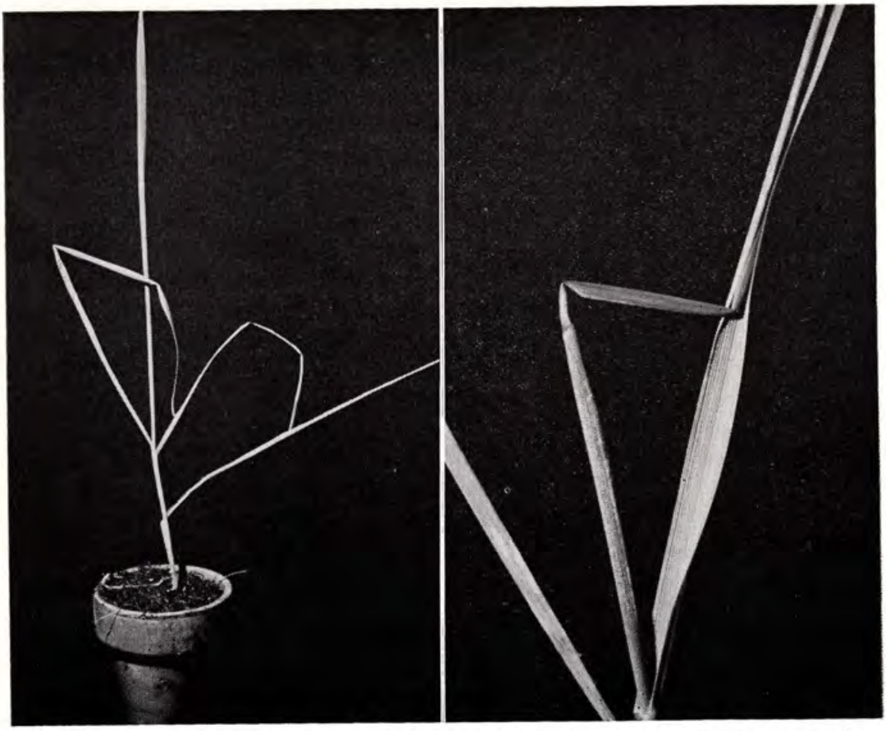


FIGURE 5.—Left, characteristic appearance of wheat plant infested with *Aceria tulipae* (K.). Note the rolled and trapped leaves. Right, the tip of an emerging leaf is caught in the rolled leaf immediately below it.

In no instance did any of the mites reared to the adult stage fail to lay fertile eggs and since these mites were caged singly without resource to other mites, it is concluded that reproduction occurred parthenogenetically. Because of the difficulty in keeping ovipositing mites in confinement, the average number of eggs produced could not be determined with any degree of refinement. Nevertheless, it was determined that at least 12 eggs were produced by each female but more detailed studies may disclose that the average egg production is somewhat in excess of this figure.

A mite-infested leaf of a young wheat plant is rolled entirely or in part from one edge of the leaf to the other parallel to the leaf veins. The entire leaf may be rolled or the basal portion of the leaf may not be rolled while the remainder of the leaf is rolled. At times neither the basal nor the apical portions of the leaf may be rolled while the portion occurring in the central area of the leaf may be rolled. Complete rolling generally is found only in the youngest leaves of seedling plants whereas the older leaves may have either the basal or apical portions not rolled. In older plants the rolling may be confined to a mere

lapping of one leaf edge with the mites being found beneath this lapped margin. As the youngest leaf of a wheat plant grows, it pushes out from the base of the leaf immediately below it. If this lower leaf is rolled, the tip of the new leaf can be caught or trapped in the older rolled leaf. Since leaf growth occurs basally, the tip of the new leaf remains trapped and the leaf becomes looped (figure 5). The mites usually progress from the older leaves to the newer leaves and thus the trapped leaves become rolled also. Leaf rolling and trapping is not necessarily an indication of a large mite population because the feeding of a small number of mites may cause the leaves to roll. Other factors than mite infestation have also been known to cause leaf rolling in wheat. Extreme leaf rolling and trapping is common in mite-infested winter wheat seedlings in the fall and in volunteer wheat seedlings in the summer. Leaf trapping generally is not apparent in winter wheat in the early spring because wind-whipping of the plants during the winter dislodges the tips of the trapped leaves. At this time mites on infested plants are usually found in the rolled youngest leaves, the mite population of the preceding fall having been decimated by the vicissitudes of winter.

## EPIDEMIOLOGICAL STUDIES IN NEBRASKA IN 1953 AND 1954

### Description of Climatic Factors in the Study Area in Western Nebraska

Observations over a three-year period in western Nebraska indicated a very close association between hail damage in winter wheat areas and epidemics of wheat streak mosaic which occurred in the following wheat crops. Therefore, when hail occurred in a large area in western Nebraska in 1953, various sites within this area were selected for detailed studies of the epidemiology of wheat streak mosaic. This area was located in Cheyenne and Kimball Counties and is illustrated in figure 6. The agriculture in this region is devoted almost entirely to the summer fallow system of hard red winter wheat production and the grazing of native grass pastures by cattle.

On July 2, 1953, a severe hail storm accompanied by driving wind and rain swept through portions of Kimball and Cheyenne Counties, leaving a totally destroyed wheat crop in its wake. Freqent rain storms occurred in Kimball County throughout the month of July with 0.99 inch reported on July 6, 0.83 inch on July 16, 0.23 inch on July 25, 1.79 inches on July 29, and 2.07 inches on July 30. Smaller amounts of rain fell frequently throughout the month with the result that the average monthly precipitation was approximately 5 inches above normal. August and September in 1953 were somewhat dry with a departure from normal in August of –.43 inch and in September of –.88 inch. The total precipitation in August was 1.38 inches and in September only .30 inch of rain fell. October also had little rainfall

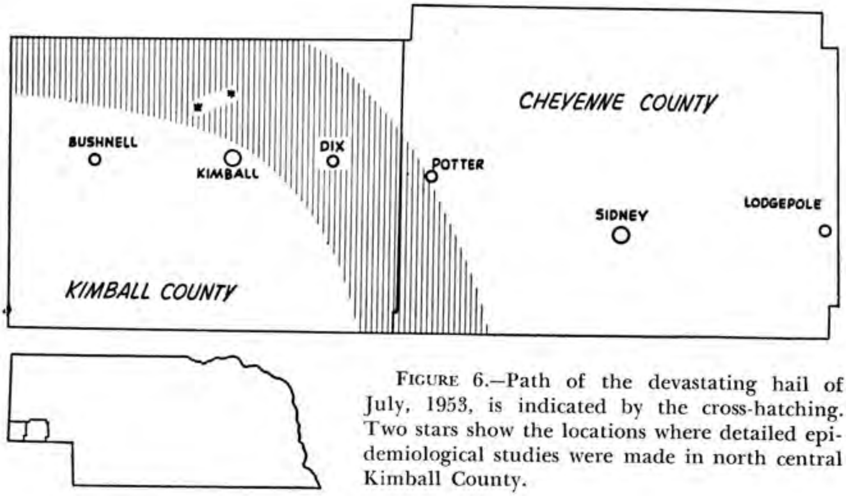
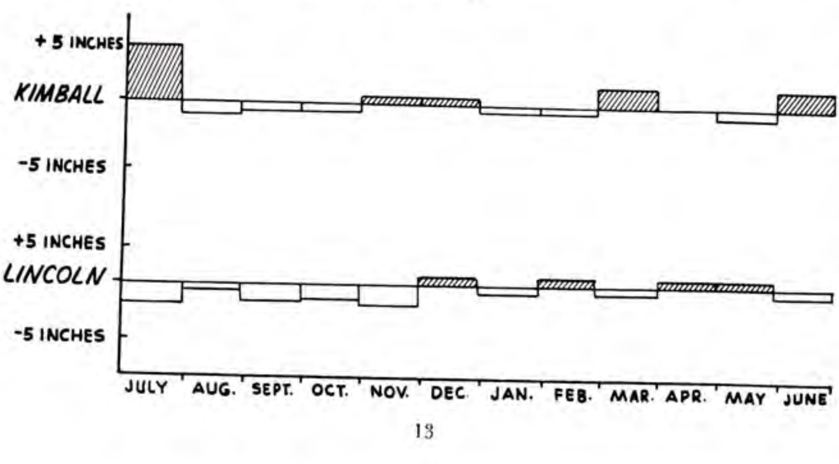



FIGURE 6.—Path of the devastating hail of July, 1953, is indicated by the cross-hatching. Two stars show the locations where detailed epidemiological studies were made in north central Kimball County.

with a total of .28 inch whereas November was .21 inch above normal with a total of .73 inch. The precipitation in December totalled .78 inch, whereas January and February of 1954 were extremely dry with .06 inch of precipitation falling in January and only .06 inch reported in February. Deviations from normal of average monthly rainfall for these and subsequent months are presented graphically in figure 7.

The average temperatures in degrees Fahrenheit in Kimball County from July 1953 through February 1954 were as follows: July, 71.4°; August, 69.4°; September, 62.9°; October, 50.5°; November, 38.7°; December, 27.4°; January, 30.3°; and February 39.7°. Departures from normal of average monthly temperatures during this period and

FIGURE 7.—Departures from normal of average monthly rainfall at Kimball and Lincoln, Nebraska for period of July 1953 to July 1954.

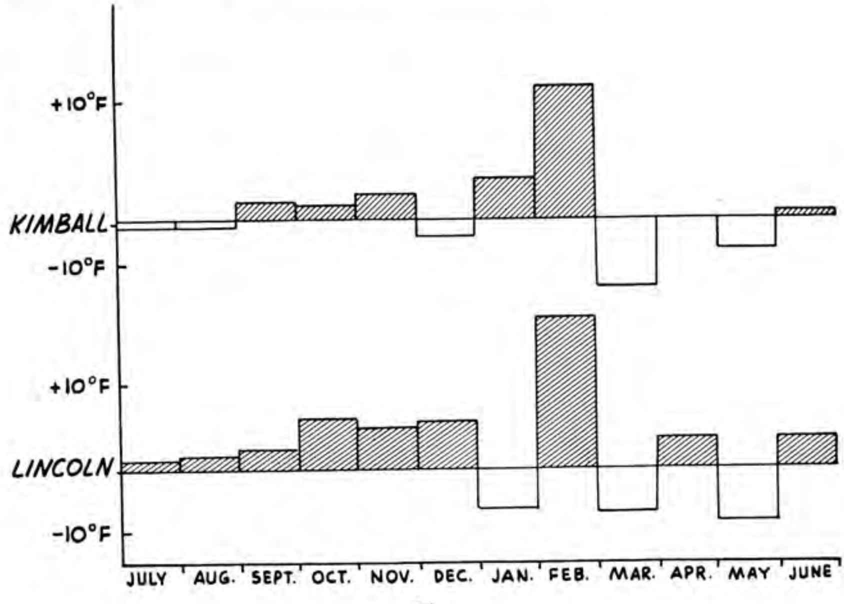


for the following months are shown in figure 8. It is noteworthy that although the monthly average temperatures at Kimball were slightly below normal for July and August, the averages for September, October and November were significantly above normal. This warm weather during these latter three months coupled with little rainfall in September and October resulted in an extended warm and dry fall. Drought conditions prevailed during the winter, particularly in January and February. Both of these months were dry with very marked positive departures from normal in average monthly temperatures.

The first pronounced frost occurred in Kimball County on September 21, when the temperature dropped to 29°. No appreciable amount of snow fell until November 19, when 3.5 inches of snow was reported.

Local precipitation and hail storms at various dates other than the far-sweeping storm of July 2, obviated any attempt at epidemiological studies throughout Kimball and Cheyenne Counties. The studies reported here therefore are concerned only with the hailed area indicated in figure 6, or comparable restricted areas nearby where there was no hail damage.

FIGURE 8.—Departures from normal of average monthly temperatures at Kimball and Lincoln, Nebraska for period of July 1953 to July 1954.



## Relationship of Volunteer Wheat to Mite Populations and Virus Incidence in the Hailed Area of Kimball County

When the shattering hail storm of July 2, 1953, struck the Kimball County area, the winter wheat crop was approximately three weeks from harvest. It has been estimated that most of the fields destroyed by the hail storm would have yielded 30 to 40 bushels per acre—thus very large quantities of grain were shattered onto the ground. With the ample moisture provided by the storm plus the additional inch of rain which fell on July 7, the grain embedded somewhat in the soil by the action of the storm soon germinated. Shallow-planted wheat kernels of a variety like Cheyenne commonly grown in western Nebraska can produce seedling plants in four or five days with optimum conditions for germination such as existed in Kimball County the first week in July. Thus by July 10, the fields in the hailed area were supporting luxuriant stands of volunteer wheat while the crop itself was still somewhat green. It has been demonstrated on numerous occasions in the greenhouse that as the leaves on wheat plants dry back, *A. tulipae* will seek the remaining green leaves. It has also been found that most Nebraska wheat fields each year contain some plants infected with wheat streak mosaic virus and harboring *A. tulipae*. It was relatively simple for *A. tulipae,* present on scattered plants in some of the fields throughout the hailed area, to transfer from the still somewhat green hailed crop to the quickly ensuing volunteer wheat seedlings. This migration was probably accomplished by means of wind dispersal. However, some mite transfer to the volunteer plants may have been brought about by the mites travelling under their own power because of the close proximity of the hailed wheat and the volunteer plants. Approximately two months elapsed between the time volunteer wheat emerged and the time winter wheat was again planted in the hailed area. During this period from approximately July 10 to September 10, *A. tulipae* could have completed at least six generations since generally the life cycle may occur in 10 days. Assuming that each female may lay at least 12 eggs, the offspring arising from any one mite present on volunteer wheat immediately after the hail storm of July 2 could be $12^6$ at the time the newly planted wheat crop was emerging in the fall. Such an estimate of population increase does not account for the environmental factors adversely affecting that population, but it does emphasize the tremendous reproductive potential of this mite species. It is not surprising, therefore, that in early September very heavy infestations of *A. tulipae* were present in most stands of volunteer wheat throughout the hailed area. This condition was typical in scores of wheat fieds examined. The infestation was so great that no attempt could reasonably be made to arrive at any numerical or quantitative expression of population density. The volunteer

plants by this time were obviously injured by the mite feeding, the rolled and trapped leaves in field after field displaying a high degree of chlorosis and necrosis.

During the first two weeks in September, surveys were made in fields of volunteer wheat in the hailed area to determine the incidence of wheat streak mosaic. Samples of plants were selected at random and inoculations were made from these samples to healthy wheat seedlings in the greenhouse employing the carborundum-wiping method. It was found that the incidence of wheat streak mosaic infection was high, ranging from 50 per cent to 100 per cent in the volunteer wheat plant samples examined.

### Mite Populations and Virus Incidence in Volunteer Wheat Outside the Hailed Area in Kimball County

By October 15, 1953, the volunteer wheat in the hailed area was practically exterminated because of excessive mite damage, wheat streak mosaic infection, and drought. Three volunteer wheat fields which had been under observation since the first week in September, when they first showed the effects of mite and virus attack, now contained from 1 per cent to 5 per cent of the original volunteer plants. The new wheat crop in the hailed area was thoroughly infected with wheat streak mosaic virus, symptoms being evident in some of the fields by the first week in October.

Surveys for mites and diseased plants were made from October 15 to October 20 in stands of volunteer wheat five to ten miles west of the hailed area. The region selected for these surveys had not been hailed and the volunteer wheat arose some time after harvest. In contrast to the volunteer wheat in the hailed area, the volunteer wheat now examined was green and thriving. The mite population was small and insignificant in contrast to that in the hailed area. Occasional plants were found bearing mites but the bulk of the plants examined were free of mites. In some of the samples of volunteer plants, rolled and trapped leaves were evident but no mites were found. Associated with this paucity of mites in the volunteer wheat outside the hailed area was the very low incidence of wheat streak mosaic. In the various stands of volunteer wheat examined, only an occasional diseased plant could be found. Unlike the situation in the hailed area, the conditions outside the hailed area were not conducive for instituting an epidemic of wheat streak mosaic in the new winter wheat crop which had emerged some five or six weeks previously.

It appeared therefore that an important factor in the epidemiology of wheat streak mosaic was the time volunteer wheat arose; that early volunteer wheat, germinating either before or immediately after harvest, was generally much more important in this respect than volunteer wheat arising several weeks after harvest. Numerous observations

since the fall of 1953 have shown that stands of volunteer wheat arising some time after harvest usually contain few mites and diseased plants at the time the winter wheat crop is planted. To gain further information on this matter, simulated volunteer wheat and natural volunteer wheat of which the time of emergence was known was examined periodically for *A. tulipae* in Kimball County during the summer of 1954.

**Mite Populations in Volunteer Wheat, Kimball County, 1954**

In 1954, an attempt was made to determine the influence of volunteer wheat arising at various times throughout the summer on mite populations. To this end, wheat was planted in disked or otherwise destroyed portions of wheat fields on July 15, and at bi-weekly intervals thereafter. All but one of these simulated volunteer plantings were failures because the detrimental effects of drought either prevented emergence or caused the seedlings to die too soon after emergence for the acquisition of the desired information. Fortunately the planting of June 15 survived and thus an opportunity was afforded to determine again the relationship of volunteer wheat, emerging before the adjacent crop matured, to population increase of *A. tulipae*. Two additional sites in the same vicinity were selected in which the dates of emergence of natural volunteer wheat were determined with accuracy and samples of 25 to 150 plants chosen at random from these stands of volunteer wheat were examined periodically. Each plant was examined thoroughly under the dissecting microscope at a magnification of 30 diameters. The results are presented in table 2.

The simulated volunteer wheat, field A in the table, was hand sown and then lightly disked on June 15. It was located in a corner of a field of wheat in which the estimated yield was later found to be between 25 and 30 bushels per acre. There was no apparent mosaic infection or damage in this field. The simulated volunteer wheat emerged on or about July 3, when the adjacent crop still possessed much green foliage. Since the disking operation at the time of sowing did not kill all original wheat growing in the simulated volunteer site, the volunteer wheat emerged among the still-green plants of the original crop. In essence, a situation parallel to that which existed in the hailed area of the previous year was established.

At the time of the first examination, July 10, the simulated volunteer was in the two-leaf stage and rolled and trapped leaves were easily found. By July 15, this stand of simulated volunteer wheat was completely infested with *A. tulipae* and remained so until about August 26, at which time for some unknown reason the mites had disappeared. These observations demonstrate (1) volunteer wheat, emerging before the crop in the vicinity has matured, is subject to mite infestation in a short period of time. The same was observed after the hail storm of

TABLE 2.—Percentage of volunteer wheat plants infested with *Aceria tulipae* (K.) in stands of volunteer wheat arising either before or after harvest (Kimball, Nebraska, 1954).

| Field designation | Date regular wheat crop in vicinity completely mature | Date of volunteer wheat emergence | Percentage of plants found to be infested with *Aceria tulipae* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | July 10 | July 15 | July 22 | July 29 | Aug. 5 | Aug. 12 | Aug. 26 | Sept. 2 |
| A | July 15 | July 3 | 40 | 94 | 100 | 98 | 100 | ...... | 0 | ...... |
| B | July 3 | July 24 | | | | 0 | 0 | ...... | 0 | 0 |
| C | July 3 | Aug. 8 | | | | | | 0 | 0 | ...... |

the preceding year. (2) Mite infestation in volunteer wheat may decline or disappear. The reasons for this phenomenon are not known. However, it has been found that under greenhouse conditions an unknown species of mesostigmatic mite may, in a short time, completely eliminate cultures of *A. tulipae.*

Fields B and C had natural stands of volunteer wheat, the former appearing 21 days and the latter 36 days after the wheat crop in the vicinity was completely mature or had been harvested. Examinations of samples of plants from these two volunteer wheat sites disclosed no mites. To determine whether *A. tulipae* were present in the neighborhood of these stands of volunteer wheat, perennial and annual native grasses were inspected. Although a very small number of mites were found on annual grasses, some of the perennial species harbored thriving colonies of *A. tulipae.* It appeared that volunteer wheat arising several days after harvest is usually free of mites, a condition which was also true outside the hailed area in Kimball County during the summer of 1953. It is reasonable to assume then that continuity of favorable food plants for the mite and hosts for the virus is important in the epidemiology of wheat streak mosaic. This occurs when volunteer wheat appears before or at least immediately after the wheat crop has matured. On the other hand, when such favorable food-plant continuity is interrupted by the appearance of volunteer wheat several weeks after harvest, the probability of an epidemic of wheat streak mosaic is less.

### Factors Involved in the Dispersal of A. tulipae by the Wind from Volunteer Wheat to the Winter Wheat Crop

*A. tulipae* is easily transported by movements of the air. This has been demonstrated by Slykhuis (1955) and Pady (1955), the former dispersing *A. tulipae* from infested to non-infested wheat in the greenhouse with a fan and also trapping mites on vaseline-coated microscopic slides both in the greenhouse and outdoors, the latter trapping mites on silicone grease covered slides 1½ to 2 miles from the nearest wheat field. The importance of the wind as the main method of mite dispersal was dramatically emphasized by trap collections from the epidemic area in Kimball County in 1953.

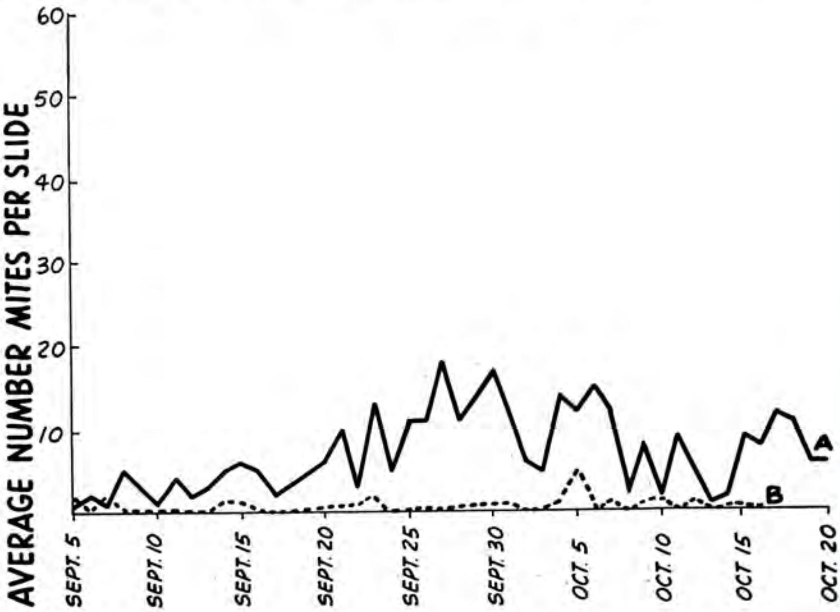
During the first two weeks of September traps were erected in four locations in the previously hailed area. Some of the traps were situated in mite-infested volunteer wheat, others on margins of winter wheat fields adjacent to the volunteer wheat while others were placed in the winter wheat fields some distance from the volunteer wheat. The traps were the familiar wind-vane type; those employed in stands of volunteer wheat were approximately 8 to 10 inches in height whereas those in fields of winter wheat were approximately 37 inches high. To determine the most expedient trap heights and trapping surfaces in vol-

unteer and winter wheat fields, a test of technique was made and the results obtained will be published later. The most satisfactory trapping surface was that of the standard glass microscope slide (25mm x 75mm). These slides were coated on one side with Dow Corning high vacuum grease, a material which resists fairly well damage from beating rain, does not change its physical characteristics noticeably with fluctuating temperatures, is optically desirable for microscopic examination of the entrapped mite specimens and does not strip from the slides when they are treated with mite clearing and staining media. The mites were cleared and stained *in situ* on the slides with Keifer's "A" solution (Keifer, 1952, page 3) and then rinsed in water.

Daily collections were made from about September 1 to October 20. This was considered to be the critical period during which a wheat crop, if infected, would be seriously injured. Certain traps remained in operation during the late fall and winter months. Slides were exposed in these traps at irregular intervals for two days at a time.

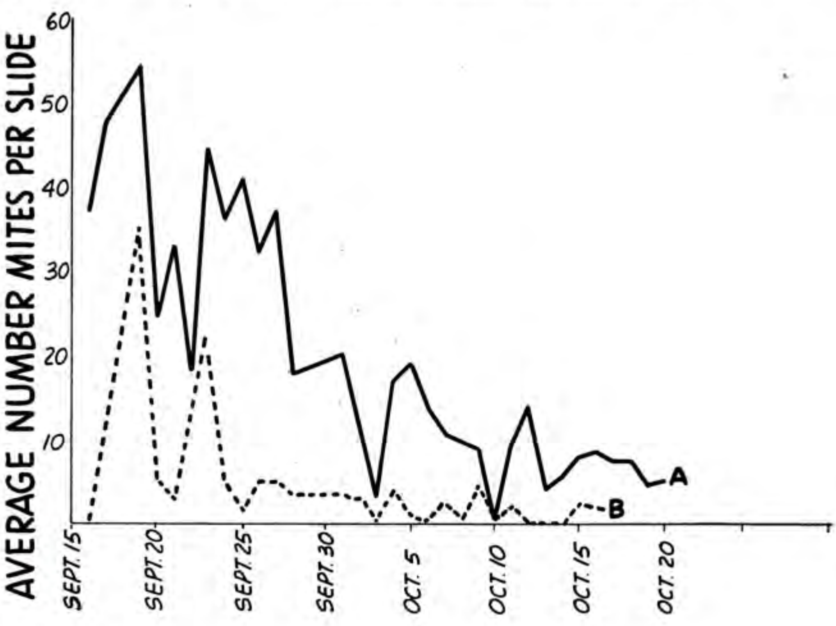
To avoid repetition, the results obtained at only two trapping locations during the critical period are considered here. In one location three traps were placed in heavily infested volunteer wheat and three

FIGURE 9.—Mite (*A. tulipae* K.) populations observed on greased slides exposed to the air in Kimball County during the critical period of virus spread. A. Average number of mites per slide from three slides exposed daily for 24 hours in the volunteer wheat which was heavily infested. B. Average number of mites per slide from three slides exposed daily for 24 hours in the newly planted wheat field approximately 105 feet from the infested volunteer wheat. (Farm No. 1, 1953).



more were placed approximately 85 feet from the volunteer wheat and 20 feet in from the margin of a field of winter wheat and another in the winter wheat field approximately 1000 feet from the volunteer wheat. The daily average trap collections from the volunteer wheat and from the winter wheat field margin are presented in figure 9. It can be seen that the greatest numbers of mites were taken from traps located within the volunteer wheat field which was the source of he infestation. Consistently smaller numbers of mites were trapped in the the edge of the newly seeded winter wheat. The mite counts from the trap farther in the wheat field were so small that it was impractical to plot the data on the graph. The greatest number of mites taken on any one day by this trap was two. At the beginning of the trapping period the volunteer wheat plants, although showing evidence of mite infestation, were green and thriving. But as the warm weather continued (see figure 8), the volunteer wheat gradually declined. With this diminishing of the volunteer wheat, the numbers of trapped mites increased, with intensive mite dispersal occurring in late September and continuing through the next two months. Collections were made from

FIGURE 10.—Mite (*A. tulipae* K.) populations observed on greased slides exposed to the air in Kimball County during the critical period of virus spread. A. Average number of mites per slide from three slides exposed daily for 24 hours in the volunteer wheat which was heavily infested. B. Average number of mites per slide from three slides exposed daily for 24 hours in the newly planted wheat field approximately 10 feet from the volunteer wheat. (Farm No. 2, 1953).



two traps in the volunteer wheat and one on the margin of the winter wheat field at various times from late October through mid-January. Traps A and B in table 3 were located in the volunteer wheat, trap C on the margin of the field of winter wheat. It is obvious that as long as warm weather continued in the fall mites were dispersed in great numbers by the wind. The mites trapped in early September necessarily originated in volunteer wheat. But those trapped in late October and November could well have arisen from infestation in either volunteer wheat or the winter wheat crop itself. The wheat in the newly planted field emerged September 2, and wheat streak mosaic infection and mite infestation were apparent as early as September 14. Samples of randomly selected wheat plants tested by manual inoculation in the greenhouse showed that 36 per cent of the plants near the mite traps and on the side of the field near the volunteer wheat were infected on October 21.

At a second study site, two traps were placed in the volunteer wheat and two on the winter wheat field margin approximately 10 feet from the mite-infested volunteer wheat. The average daily mite counts from these traps during the critical period are shown in figure 10 and the numbers of mites trapped at various times during the late fall by the traps in the volunteer wheat (traps D and E) and one trap on the winter wheat field margin (trap F) are presented in table 3. At this site, the mite infestation in the volunteer wheat was greater than that at the site already described and this is reflected in the numbers of mites trapped at each location (contrast figure 9 with figure 10). Because of the combined effects of drought, abnormally high temperatures and extreme mite injury, the volunteer wheat deteriorated more quickly than in the previous study site. Thus a great mite migration occurred during September and gradually declined until late November. Here again the mite catch was smaller in the edge of the newly planted wheat but proportionally more mites in relation to those trapped in the volunteer wheat were taken than in the former study site, probably because the traps on the winter wheat field margin were situated much closer to the source of mite infestation. The volunteer wheat at both study sites was completely infected. The limiting factor governing the incidence of disease in the adjacent winter wheat crop in both sites was the relative mite population in the volunteer wheat and the proximity of the winter wheat crop to the mite source. Thus manual inoculations from random samples of wheat emerging the first week in September in the newly planted field at this second study site indicated that 81 per cent of the plants were infected on September 22 and 100 per cent on December 1. Fields of winter wheat that emerged at approximately the same time in the epidemic area were not equally exposed to viruliferous *A. tulipae*. The distance separating the winter wheat field from volunteer wheat, the amount of inoculum and the

TABLE 3.—Mite collections during the late fall and winter from traps in volunteer wheat and the margins of winter wheat fields, epidemic area, Kimball County, 1953-1954.

| Trap designation | Location of trap | | Number of mites trapped during period of: | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Oct. 26-27 | Nov. 2-3 | Nov. 10-11 | Dec. 2-3 | Dec. 14-15 | Dec. 29-30 | Jan. 7-9 | Jan. 13-14 |
| Trap A | Volunteer wheat | Field 1 | 42 | 5 | 117 | .... | .... | 0 | 1 | 0 |
| Trap B | Volunteer wheat | Field 1 | 69 | 11 | 116 | 0 | 0 | 0 | .... | 0 |
| Trap C | Field margin | Field 1 | .... | 7 | 11 | .... | .... | .... | .... | .... |
| Trap D | Volunteer wheat | Field 2 | 88 | .... | .... | 0 | 0 | .... | 0 | 1 |
| Trap E | Volunteer wheat | Field 2 | 22 | 12 | 66 | 0 | 0 | 0 | 6 | 1 |
| Trap F | Field margin | Field 2 | .... | 13 | 108 | .... | .... | .... | .... | .... |

degree of mite infestation in the volunteer wheat associated with the condition of the volunteer wheat were important elements in determining the incidence of disease in any winter wheat field.

The temperature in December was markedly below normal (see figure 8). With cessation of warm temperatures and particularly after the snowfall of November 19, no mites were trapped in either of the two study areas during December (table 3). The weather ameliorated in January, so much so that above normal temperatures occurred. Again mites were dispersed by the wind as indicated by the trap collections during that month. It appears that *A. tulipae* may be windborne during warm periods in the winter and that mite migration may take place during any month of the year. However, mite dispersal during the winter is of very dubious significance in the epidemiology of wheat streak mosaic in the Nebraska winter wheat crop.

## Mite Dispersal Correlated with Wind Velocity and Daily Temperatures

It would seem obvious that the dispersal of any small animal the size of *A. tulipae* would be influenced by wind velocity. However, colonies of *A. tulipae* generally are located in tightly rolled wheat leaves and therefore are protected from the wind. If the activity of these mites were associated with temperature, wind velocity might not be of importance in mite migration unless sufficiently high temperatures prevailed to increase mite activity to the point that many of them would forsake the protection afforded by the rolled leaves.

At the time each day when the trap slides were collected, estimates of the wind velocity were made. An array of the average daily number of mites obtained in 23 days from September 15 to mid-October, with the corresponding estimated wind velocities, is presented in table 4. Each

TABLE 4.—Array of 23 average daily mite trap collections and corresponding daily estimated wind velocities, Kimball County, September 15 to October 15, 1953.

| Average number of mites per slide in order of magnitude | Estimated wind velocity mph |
|---|---|
| 20.7 | 30 |
| 14.6 | 10 |
| 14.4 | 15 |
| 14.0 | 15 |
| 13.9 | 10 |
| 12.9 | 30 |
| 11.4 | 5 |
| 10.8 | 25 |
| 10.6 | 5 |
| 9.7 | 8 |
| 7.9 | 15 |
| 7.6 | 15 |
| 7.6 | 12 |
| 6.9 | 5 |
| 6.2 | 12 |
| 6.1 | 3 |
| 5.4 | 15 |
| 5.4 | 12 |
| 4.9 | 0 |
| 4.8 | 10 |
| 2.7 | 10 |
| 2.5 | 15 |
| 1.6 | 10 |

Correlation coefficient, $r = 0.4703$*
Correlation coefficient, $r_{0.05}$ with 21 df $= 0.413$

TABLE 5.—Array of 20 average daily mite trap collections and corresponding daily maximum, minimum and mean temperatures, Kimball County, September 15-October 15, 1953.

| Average number of mites per slide in order of magnitude | Corresponding daily temperatures, degrees F. | | |
|---|---|---|---|
| | Minimum | Maximum | Mean |
| 20.7 | 43 | 84 | 63.5 |
| 14.6 | 50 | 86 | 68.0 |
| 14.4 | 29 | 70 | 49.5 |
| 14.0 | 32 | 82 | 57.0 |
| 13.9 | 27 | 67 | 47.0 |
| 12.9 | 52 | 84 | 68.0 |
| 11.6 | 40 | 71 | 55.5 |
| 11.4 | 48 | 82 | 65.0 |
| 10.8 | 45 | 86 | 65.5 |
| 10.6 | 40 | 87 | 63.5 |
| 9.7 | 29 | 71 | 50.0 |
| 7.9 | 42 | 69 | 55.5 |
| 7.6 | 40 | 88 | 64.0 |
| 6.9 | 47 | 84 | 65.5 |
| 6.2 | 44 | 82 | 63.0 |
| 6.1 | 40 | 78 | 59.0 |
| 5.4 | 37 | 83 | 60.0 |
| 4.9 | 32 | 67 | 49.5 |
| 2.1 | 39 | 82 | 60.5 |
| 1.6 | 35 | 77 | 56.0 |
| Correlation coefficient, r | 0.0937 | 0.0656 | 0.0876 |
| Correlation coefficient, $r_{0.05}$ with 18 df = 0.444 | | | |

figure representing the average daily number of mites was computed from the collections of 10 traps located in volunteer wheat at four different locations throughout the epidemic area of Kimball County, 1953. The correlation coefficient, 0.4703 is significant at the 5 per cent level and thus mite dispersal is correlated with wind velocity.

In table 5, the daily average numbers of mites per slide from 10 slides obtained from traps in volunteer wheat are arrayed with the corresponding daily maximum, minimum and mean temperatures. The slides were exposed to the air for 20 days from September 15 into October in the epidemic area of Kimball County in 1953. The mean temperatures presented in the table are averages of the maximum and minimum temperatures. Maximum temperatures between 67° and 88° F. had no influence on mite dispersal, the correlation coefficient being 0.0656. Minimum temperatures between 29° and 52° F. also had no effect, the correlation coefficient in this instance being 0.0937. The correlation coefficient for mean daily temperatures is 0.0876 and mean temperatures between 47° and 68° F. apparently did not influence the migration of *A. tulipae.* These temperatures are typical of those occurring during September and October in Nebraska. Thus it appears that temperature generally is not important in the dispersal of *A. tulipae* during the period in which the winter wheat crop is usually infected with wheat streak mosaic virus.

## Mite Dispersal as Influenced by Topographic Features

In the epidemic area in Kimball County in the autumn of 1953, attempts were made to determine the influence of certain topographic features on mite dispersal and virus spread. At one location a field of heavily infested and infected volunteer wheat was situated to the west and across a highway from a windbreak. This windbreak consisted of a double row of trees, approximately 20 feet high. Immediately to the east of the windbreak was a field of winter wheat, some 150 feet from the volunteer wheat which was the sole mite source for several miles. Observations on disease incidence and mite infestation were made in this winter wheat adjacent to the windbreak to determine whether the intervening trees might decrease the influx of mites. The winter wheat alongside the windbreak became thoroughly diseased and infested and the windbreak was not effective in protecting that portion of the winter wheat field. Approximately 500 yards from the volunteer wheat, this same winter wheat field dipped sharply into a deep vale and again observations were made to determine whether the slope nearer the volunteer wheat might be protected from viruliferous mites. The wheat in this vale became uniformly infected and infested and this topographic feature in no way influenced the incidence of either mites or virus. No evidence was obtained therefore that topographic features affected the dispersal of *A. tulipae*.

## Time of Wheat Emergence as Related to Disease Incidence

Immediately adjacent to a field of mite-infested and diseased volunteer wheat in the epidemic area in Kimball County (Field No. 2 discussed in a previous section) the winter wheat was planted in strips on different dates. These strips ran at a right angle to the volunteer wheat field, an arrangement which resulted in equal exposure of all the strips to mite dispersal from the volunteer wheat. Mite traps located in the volunteer wheat and on the margin of the winter wheat field gave the results already discussed and presented in figure 10 and table 3 (traps D, E and F). On December 1, samples of 100 plants from each strip in the newly planted wheat were taken at random at 40 to 50 feet from the margin of the field and manual inoculations were made from each plant in these samples to

TABLE 6.—Effect of date of planting on the incidence of streak mosaic of wheat under extremely severe conditions for infection at one location in western Nebraska (Farm No. 2, 1953).

| Planting date | Plants infected Dec. 1 |
|---|---|
| | per cent |
| Aug. 17 | 100 |
| Aug. 22 | 100 |
| Aug. 29 | 98 |
| Sept. 5 | 94 |
| Sept. 12 | 66 |
| Sept. 19 | 46 |
| Sept. 26 | 30 |
| Oct. 3 | 24 |
| Oct. 10 | 6 |

healthy wheat seedlings in the greenhouse. The data for this date of planting experiment are given in table 6. The effect of date of planting is quite marked. The later the date of planting the lower the percentage of infection. This correlation between date of planting and disease incidence probably can be accounted for by the decreased exposure of the late-planted wheat to viruliferous mites. This would be particularly true if the wheat crop were infected noticeably by intra-field spread of the virus.

### Effect of Time of Infection on Yield and Quality

With most plant virus diseases, plants infected soon after emergence are more seriously damaged than plants infected at a much later time. This was suspected for wheat streak mosaic after numerous spring surveys of diseased winter wheat fields disclosed various degrees of symptom expression in diseased plants, varying from complete necrosis in some plants to the first faint initial mottling in others. It was also noted that those plants showing primary symptoms in the spring were not seriously damaged whereas those displaying advanced symptoms usually were greatly affected.

An experiment to determine the effect of time of infection on yield and quality was started in Lincoln during the autumn of 1952. Each plot consisted of three rows 1 rod long, the center row furnishing the yield data. Each treatment was replicated four times. The wheat for the entire experiment was planted approximately five days before the first series of inoculations was made on October 1. Subsequent series of inoculations in the fall were made at intervals of two to three weeks depending upon suitable weather conditions for field operations. The last series of inoculations was made the following spring, on April 15. Inoculations were made by rubbing an inoculum-carborundum mixture with the fingers on all the plants in each of the plots. The streak mosaic virus culture used in this test consisted of a relatively mild strain obtained from wheat in western Nebraska. No spread of the virus to plants escaping initial infection from the manual inoculations was observed in any of the treatment plots. The checks or uninoculated plots were carefully inspected during the course of the experiment but no infection was detected. Late in the spring, samples of plants from inoculated and uninoculated plots were tested for the presence of infective virus by mechanical inoculations to healthy wheat seedlings in the greenhouse. Although a high percentage of the inoculated plants were found to be infected, no disease was present in the uninoculated plants. The disease incidence in the various inoculated plots was very uniform with 75 to 80 per cent of the plants being infected.

The results of this experiment are presented in table 7. It is obvious that infection occurring early in the development of the wheat plants distinctly reduced the yield. It is questionable however, that the test

TABLE 7.—Effect of time of infection with wheat streak mosaic virus on the yield and test weight of Pawnee wheat, Lincoln, Nebraska, 1953.

| Time infected | Av. yield bu. per A. | Av. test weight lb. per bu. |
|---|---|---|
| No infection | 42.1 | 60.2 |
| October 1 | 25.5** | 57.0 |
| October 19 | 37.9* | 60.5 |
| November 11 | 39.3 | 59.5 |
| November 23 | 46.1 | 61.0 |
| April 15 | 39.5 | 59.5 |

* LSD 5% 4.1
** LSD 1% 5.7

weight was adversely affected except possibly in the wheat obtained from those plots inoculated on October 1. It is probable that improvements in inoculation techniques and more recent knowledge of virus strains could lead to a more dramatic demonstration of the effect of time of infection on yield and quality. Improved methods of inoculation would result in practically all the plants in the inoculated treatments becoming infected. The use of more damaging strains of the virus probably would result in the plants inoculated early in their development yielding but a trace of grain.

The results of this experiment indicate (1) that spring infection of the winter wheat crop is not necessarily damaging, (2) that wheat emerging relatively early in the fall and infected soon after emergence is seriously damaged, (3) that wheat emerging early in the fall but escaping infection until a much later time is not necessarily injured to the same extent. It is a mute point whether wheat emerging later in the fall and infected soon after emergence is impaired to the same extent as wheat arising earlier and also infected immediately after emergence. However, wheat emerging later in the fall in the epidemic area of Kimball County and infected soon after emergence, although less diseased than earlier planted wheat, was markedly damaged. In this instance the prolonged warm autumn weather may have influenced virus multiplication in later-emerging wheat to the detriment of the wheat plant. Time of wheat emergence in relation to the debilitating effects of virus infection is possibly correlated with the duration of suitable temperatures for virus multiplication to progress to the point that infection becomes systemic.

## Effect of Wheat Streak Mosaic Infection in Relation to Overwintering of the Wheat Crop

An examination of figure 8 will disclose that the period from January to March of 1954 favored winterkilling in the wheat crop in Kimball, County. The abnormally warm weather in January and particularly in February promoted wheat growth but unusually cold

weather followed in March. As a consequence, throughout the county, wheat was killed on knolls and other exposed places. In the epidemic area this winterkilling was much more pronounced than outside the epidemic area. In many of the wheat fields, few diseased plants could be found late in the spring, the diseased plants having succumbed during the winter. A causal relationship between wheat streak mosaic infection and winterkilling could only be established by a prior knowledge of the high disease incidence in the winter wheat crop the preceding fall and by comparing the degree of winterkilling in and out of the epidemic area. Under certain circumstances it may be impossible in the spring to determine the incidence of wheat streak mosaic in the winter wheat crop. If severe winter conditions prevail, disease-weakened plants may fail to survive.

### Effect of Miticides on the Incidence of Wheat Streak Mosaic in the Winter Wheat Crop

Laboratory screening of various miticides indicated that demeton and parathion were more effective than Metacide, malathion, Ovatran and Aramite against *A. tulipae*. The technique employed consisted of dipping mite-infested wheat plants in emulsions of these miticides and estimating mortality 24 hours after treatment. Parathion appeared considerably more effective than systox, but since systox was more effective than the other miticides tested, it was decided to use both of these materials in the epidemic area of Kimball County during the early fall of 1953 to determine whether their use might decrease the incidence of wheat streak mosaic. Systox at 1 pint per acre and parathion at 1 quart per acre were applied in five similar field experiments on September 12. The miticides were sprayed at 15 gallons per acre and 40 pounds pressure. Each plot was 25 by 100 feet and each treatment was replicated three times. The wheat in the experimental fields at the time of spray application was in the two-leaf stage, having emerged approximately seven days before. Estimates of the amount of disease in each plot were made two months after application and again the following spring. No differences between treated and check plots in any of the five experiments were evident and one application of these chemicals was worthless in reducing the incidence of wheat streak mosaic.

Under the conditions existing in the epidemic area of Kimball County it would have been remarkable indeed if one application of any miticide had decreased the amount of disease. To spray just as the wheat is emerging from the soil and only ½ to 1 inch in height would hardly be feasible because of the poor coverage of the eventual stand of wheat plants. To spray when the wheat is larger and at least in the two-leaf stage exposes the wheat to viruliferous mites for a week or so before chemical application is made. Furthermore, the miticide

employed must kill mites very soon after they have been wind-borne into the winter wheat to prevent inter-field spread of the virus. Apparently infection may take place after a viruliferous mite has fed for only a minute or so. There is little possibility of eliminating such mites with miticides soon enough to prevent infection. Moreover, the miticide must also provide long residual action—the residual action would have had to persist for at least two months in the Kimball County epidemic area.

The use of miticides on the winter wheat crop to protect it against wheat streak mosaic infection seems considerably less promising when it is realized that epidemics are not yearly occurrences, that they rarely reoccur in the same wheat-growing area, and that generally an epidemic is not noted until disease symptoms appear on the wheat in the spring. Usually wheat growers are not aware of an incipient epidemic at the time wheat is planted in the fall. The experience in Kimball County was an exception rather than the rule in this respect. Therefore, to advise the use of miticides on the winter wheat crop in the fall is not practical, not only because of the limitations of one application in protecting the crop but also because the odds are favorable that the crop is not threatened by wheat streak mosaic. To suggest the use of miticides as a form of insurance against wheat streak mosaic infection would seem unwarranted unless it were established that such wheat actually is threatened.

### Native Annual Grasses as Hosts of A. tulipae and Possible Role of Such Grasses in the Epidemiology of Wheat Streak Mosaic

Several species of native annual grasses have been reported susceptible to manual inoculation with wheat streak mosaic virus or to be infected naturally (McKinney and Fellows, 1951; Slykhuis, 1952; Sill and Connin, 1953). These susceptible annual grasses form a large reservoir of virus, apparently posing a constant threat to the wheat crop. The question arises, however, as to the efficiency of these annual grasses as hosts of the vector of wheat streak mosaic virus. In order to be important in the epidemiology of wheat streak mosaic, it is not only necessary that these annual grasses provide a source of virus but also that they are suitable hosts for *A. tulipae.* The native species of annual grasses commonly found infected with wheat streak mosaic in Nebraska, particularly in the western regions of the state where epidemics of wheat streak mosaic are more prevalent, are green foxtail, *Setaria viridis* (L.) Beauv., stinkgrass, *Eragrostis cilianensis* (All.) Link and witchgrass, *Panicum capillare* L. These species were found infected with wheat streak mosaic in the Kimball County epidemic area and in other areas of Nebraska in other years. To determine the ability of these three common grasses and yellow foxtail, *Setaria lutescens* (Weigel) Hubb., to serve as hosts for *A. tulipae,* they were in-

fested with mites in the greenhouse. The numbers of mites developing on these grasses were compared with those on wheat. At the time of mite transfer, the witchgrass and stinkgrass plants were 4 to 5 inches in height and had not commenced to tiller. The two *setaria* species were 6 to 8 inches with 2 or 3 tillers per plant. The wheat was 6 inches in height and in the two-leaf stage. One, four and sixteen mites were transferred to various numbers of these plants employing a brush consisting of a single hair, care being taken to insure that each mite was successfully moved to each plant. The test plants were kept at 80° to 90° F. for a month and then each plant was torn apart and examined under the dissecting microscope. The results are presented in table 8. It is clear that these species of annual grasses commonly found infected with wheat streak mosaic in Nebraska are not hosts on which *A. tulipae* can survive for any length of time.

Slykhuis (1955) reported on the susceptibility of 11 species of wild annual grasses to *A. tulipae*. These included wild oats, *Avena fatua* L., Japanese brome, *Bromus japonicus* Thunb., cheat, *Bromus secalinus* L., downy brome, *Bromus tectorum* L., crabgrass, *Digitaria sanguinalis* (L.) Scop., barnyard grass, *Echinochloa crusgalli* (L.) Beauv., stinkgrass, *Eragrostis cilianensis* (All.) Link, witchgrass, *Panicum capillare* L., yellow foxtail, *Setaria lutescens* (Weigel) Hubb., bristly foxtail, *Setaria verticillata* (L.) Beauv. and green foxtail, *Setaria viridis* (L.) Beauv. A "few mites" survived on stinkgrass, barnyard grass, bristly foxtail and green foxtail but the time during which the mites maintained themselves on these grasses is not mentioned. These species were successfully inoculated with wheat streak mosaic both manually and with mites.

Connin (1956) also determined the reaction of a series of native annual grasses to infestation by *A. tulipae*. The grass species tested included jointed goatgrass, *Aegilops cylindrica* Host., downy brome, *Bromus tectorum* L., sandbur, *Cenchrus pauciflorus* Benth., smooth crabgrass, *Digitaria ischaemum* (Schreb.) Muhl., crabgrass, *Digitaria sanguinalis* (L.) Scop., goosegrass, *Eleusine indica* (L.) Gaertn., stinkgrass, *Eragrostis cilianensis* (All.) Link, teosinte, *Euchlaena mexicana* Schrad., witchgrass, *Panicum capillare* L., and green foxtail, *Setaria viridis* (L.) Beauv. At the end of 21 days, fair to good mite infestations were found on jointed goatgrass, good infestations on sandbur and fair to good infestations on smooth crabgrass. The remainder either had very poor infestations or no infestations at that time. No mites were found on downy brome, witchgrass and green foxtail four days after initial infestation.

During the summer of 1954 an extensive survey for *A. tulipae* on native annual and perennial grasses was made from July 1 through August 15 in the Kimball county area where the epidemic had occurred the year before. Each week samples of various grass species were col-

TABLE 8.—Number of *Aceria tulipae* (K.) on four species of wild annual grasses and wheat one month after infestations with 1, 4 and 16 mites, greenhouse experiment held at 27°-30° C.

| Grass species | No. mites transferred | No. plants to which mites transferred | No. plants infested after one month | No. mites per infested plant | No. eggs per infested plant |
|---|---|---|---|---|---|
| *Setaria lutescens* | 1 | 12 | 0 | 0 | 0 |
| do | 4 | 12 | 0 | 0 | 0 |
| do | 16 | 12 | 0 | 0 | 0 |
| *Setaria viridis* | 1 | 12 | 0 | 0 | 0 |
| do | 4 | 12 | 0 | 0 | 0 |
| do | 16 | 12 | 2 | 2 | 0 |
| *Panicum capillare* | 1 | 4 | 0 | 0 | 0 |
| do | 4 | 3 | 0 | 0 | 0 |
| do | 16 | 3 | 0 | 0 | 0 |
| *Eragrostis cilianensis* | 1 | 10 | 0 | 0 | 0 |
| do | 4 | 10 | 0 | 0 | 0 |
| do | 16 | 10 | 0 | 0 | 0 |
| *Triticum vulgare* | 1 | 12 | 12 | 500+[1] | 100+[1] |
| do | 4 | 12 | 12 | 500+[1] | 100+[1] |
| do | 16 | 12 | 12 | 500+[1] | 100+[1] |

[1] No attempt was made to count more than 500 mites or 100 eggs. Infestation at such a level was considered sufficient to consider the host plant favorable for *A. tulipae* (K.).

lected in areas where mite populations had been high the previous fall and spring. These samples were carefully examined by tearing the plants apart and inspecting them under the dissecting microscope. The presence of *A. tulipae* in the survey area was verified by infestations invariably found on western wheatgrass, *Agroypron smithii* Rydb. The common species of annuals encountered were green foxtail, *Setaria viridis* (L.) Beauv., witchgrass, *Panicum capillare* L., and stinkgrass, *Eragrostis cilianensis* (All.) Link. Occurring less frequently were sandbur, *Cenchrus pauciflorus* Benth. and yellow foxtail, *Setaria lutescens* (Weigel) Hubb. At the time of the survey the abundant downy brome, *Bromus tectorum* L., was mature and few green plants were found for examination.

Of the many samples of green foxtail examined, only 11 mite-infested plants were encountered and these with only one or two mites per plant. One mite was found on a witchgrass plant and all the samples of stinkgrass were mite-free. No eggs were discovered on any of these grass species. No mites were present on the samples of sandbur and only one mite was taken on yellow foxtail. One mite was found on each of two plants of downy brome.

The results obtained in this field survey are comparable with those obtained in the greenhouse by the authors and by Slykhuis and Connin although Connin reports jointed goatgrass, smooth crabgrass and sandbur as being fair to good hosts. But jointed goatgrass is a winter annual and thus would be of no importance in the oversummering of *A. tulipae*. Smooth crabgrass is not commonly found in the vicinity of wheat fields, particularly in western Nebraska. Sandbur in nature was not found to be a host for *A. tulipae*. The plants examined, however, were fully grown, whereas Connin employed seedlings. As has been indicated by Connin (1956) and Slykhuis (1955) the degree of maturity of a grass species may influence its suitability as a host for *A. tulipae*. The infestations on wheat, sorghum and other grass species decreased as the plants matured. In some instances thriving mite colonies were maintained only when the host plants were seedlings.

It appears from the information available that annual grasses are not of any great importance in the epidemiology of wheat streak mosaic in Nebraska. Although they may serve as a reservoir of wheat streak mosaic virus, they are deficient in an epidemiological sense because they are poor hosts for the vector of this virus. Although it is possible that under very favorable conditions, viruliferous mites from diseased annual grasses might establish foci of infection in either volunteer wheat or in the winter wheat crop itself, it would seem a remote possibility. With very small numbers of *A. tulipae* occurring on such grasses, the probability is exceedingly slight that very many mites may be transported to wheat, either cultivated or volunteer.

**Native Perennial Grasses as Hosts of A. tulipae and the Possible Role of Such Grasses in the Epidemiology of Wheat Streak Mosaic**

Slykhuis (1955) determined the susceptibility of 14 species of perennial grasses to wheat streak mosaic virus by manual inoculation and mite transmission and determined the suitability of 16 perennial grasses as hosts for *A. tulipae.* Viruliferous mites infected only Canada wild rye, *Elymus canadensis* L. All the other grass species tested were apparently immune to wheat streak mosaic virus. However, attempts at rearing *A. tulipae* on Canada wild rye grass were not successful. Only two grass species, Canada bluegrass, *Poa compressa* L. and Indian ricegrass, *Oryzopsis hymenoides* (R. & S.) Ricker were found to be hosts for *A. tulipae.*

Connin (1956) ascertained the reaction of 14 perennial grasses to infestation by viruliferous *A. tulipae.* Four species were found capable of harboring mites. Poor to fair infestations occurred on western wheatgrass, *Agropyron smithii* Rydb., good infestations on an undetermined species of *Bouteloua,* fair infestation on Canada wild rye, *Elymus canadensis* L. and good infestations on Johnson grass, *Sorghum halepense* (L.) Pers. Mites transmitted the virus only to the undetermined species of *Bouteloua.*

The species of perennial grasses examined in the 1954 survey in western Nebraska were western wheatgrass, *Agropyron smithii* Rydb., slender wheatgrass, *Agropyron trachycaulum* (Link) Steud., crested wheat grass *Agropyron desetorum* (Fisch.) Schult., green needlegrass, *Stipa viridula* Trin., needle-and-thread, *Stipa comata* Trin. and Rupr., Canada wild rye, *Elymus canadensis* L., blue grama, *Bouteloua gracillis* (H.B.K.) Lag., sand dropseed, *Sporobolus cryptandrus* (Torr.) Gray, Wheeler's bluegrass, *Poa nervosa* (Hook.) Vasey, sand reedgrass, *Calamolvifa longifolia* (Hook.) Scribn., Indian ricegrass, *Oryzopsis hymenoides* (R. & S.) Ricker and smooth brome, *Bromus inermis* Leyss. Mites were discovered on five of these species, viz. western wheatgrass, needle-and-thread, Canada wild rye, Wheeler's bluegrass and Indian ricegrass. As reported by Painter and Schesser (1954), western wheatgrass was an especially good host for *A. tulipae.* All of the many samples of this grass disclosed extensive colonies of *A. tulipae,* particularly in the whorls of the developing leaves. Western wheatgrass could be important in the epidemiology of wheat streak mosaic except that it is immune to wheat streak mosaic virus (Sill and Connin, 1953). Both Connin (1956) and Slykhuis (1955) state that this grass was incapable of being infected by viruliferous mites.

Canada wild rye was found to be less susceptible to *A. tulipae* than was western wheatgrass. In only two of the samples were flourishing infestations discovered on young plants, the mites being present in the whorls of developing leaves or on heads just emerging from the

boot. Slykhuis (1955) reports that attempts at rearing *A. tulipae* on this grass species were unsuccessful but Connin (1956) obtained fair infestations when he transferred mites from wheat to Canada wild rye seedlings. McKinney and Fellows (1951) report that Canada wild rye is susceptible to wheat streak mosaic, being either a symptomless carrier or else displaying local lesions or mosaic symptoms. Connin (1956) avers that viruliferous *A. tulipae* were incapable of infecting this grass species.

Wheeler's bluegrass and Indian ricegrass are less common than either western wheatgrass or Canada wild rye in western Nebraska. Two samples of Indian ricegrass were found harboring all stages of *A. tulipae* but in neither case were the infestations equivalent to those encountered on western wheatgrass. Indian ricegrass has coriaceous leaves which are rolled naturally. Moderate numbers of mites and eggs were found deep between the veins of these rolled leaves. McKinney and Fellows (1951) found that this species infected by manual inoculation is a symptomless carrier. Slykhuis (1955) reared moderate populations of *A. tulipae* on young plants of Indian ricegrass.

Only one sample of Wheeler's bluegrass was discovered with mites and eggs. The leaves of this species tend to be folded along the midveins and the mites were situated along the entire leaf. No information is available on the susceptibility of this species to wheat streak mosaic infection. Slykhuis (1955) found that Canada bluegrass could not be infected with either viruliferous mites or by manual inoculation. However, McKinney and Fellows (1951) state that *Poa bulbosa, Poa compressa* and *Poa stenantha* are all susceptible to wheat streak mosaic virus.

One to six mites were found on each of several needle-and-thread plants. No eggs were seen and thus this species probably is one on which *A. tulipae* does not increase.

During the summer of 1954 an attempt was made to determine the movement of *A. tulipae* from western wheatgrass to nearby volunteer wheat. A stand of western wheatgrass was discovered thoroughly infested with mites and located approximately 10 yards from a field of volunteer wheat. Although samples of volunteer wheat collected immediately adjacent to the western wheatgrass were examined over a period of four weeks, no mites were found. Slykhuis (1955) determined that *A. tulipae* obtained from field-collected foxtail barley, *Hordeum jubatum* L., Canada wild rye, *Elymus canadensis* L., and western wheatgrass, *Agropyron smithii* Rydb. would not survive on wheat and that mites reared on wheat would not survive on these three species of grasses. He postulated that strain differences in *A. tulipae* account for this host specificity. Connin (1956) to the contrary transferred mites successfully from wheat to Canada wild rye and western wheatgrass and from these two grasses back to wheat.

The importance of perennial grasses in the epidemiology of wheat streak mosaic is rather difficult to determine. The most common of these perennials in western Nebraska, western wheatgrass, is a good host plant for *A. tulipae* but is immune to wheat streak mosaic. Thus western wheatgrass would appear to be of little direct importance in wheat streak mosaic epidemiology because it fails to provide a source of inoculum. Canada wild rye is another common perennial and is susceptible to wheat streak mosaic virus. Occasionally mites are found on this host and it is conceivable that viruliferous mites may be windborne from infected Canada wild rye plants to wheat. Two less common perennial grasses, Indian ricegrass and Wheeler's bluegrass, are infrequently found infested with *A. tulipae* and the former species is capable of being infected with wheat streak mosaic virus. Here again viruliferous mites are possibly transported from a perennial grass to wheat. It appears that perennial grasses may be more important than annuals in providing an interim host for mites and virus from wheat harvest to the emergence of volunteer wheat. Normally, however, it appears that mites and virus derived from either annual or perennial grasses do not develop to epidemic proportions in either cultivated or volunteer wheat. Rather, they may be thought to provide the non-epidemic quantity of wheat streak mosaic found in some wheat fields year after year. On the basis of the information now available annual and perennial grasses seem relatively unimportant in the epidemiology of wheat streak mosaic in Nebraska.

### Wheat Streak Mosaic in Eastern Nebraska, 1954

During the spring of 1954 when the devastating epidemic of wheat streak mosaic ruined the wheat crop in Kimball County in western Nebraska, a relatively minor epidemic occurred in eastern Nebraska mainly in an area south of Lincoln in Lancaster and Gage Counties. Spring surveys of the winter wheat fields in this area showed that infection was sporadic, some of the wheat fields displaying streak mosaic symptoms and others being practically devoid of diseased plants. Infected wheat was not seriously damaged. It appeared that infection occurred rather late the preceding fall and in the spring because no symptoms were seen until late March and early April whereas with comparable fall temperatures in western Nebraska symptoms appeared a few weeks after the wheat emerged.

Rainfall in eastern Nebraska during the fall of 1953 was below normal. This is graphically represented in figure 7 for the vicinity of Lincoln. In spite of this dearth of moisture, satisfactory growth of newly planted wheat took place. The critical climatological factor, however, which may well have influenced the occurrence of wheat streak mosaic was temperature. As shown in figure 8, temperatures at Lincoln were much above normal for most of the fall and winter

months. Even though the mite population in the newly emerged winter wheat may have approximated that occurring in the average autumn, the abnormally prolonged warm fall and winter weather would have provided ample opportunity for the mites to increase greatly in the winter wheat crop. It is conceivable that under such circumstances intra-field spread of the virus was more important than inter-field spread. Such warm weather would also have favored infection becoming systemic in the wheat plants.

Since the epidemic in eastern Nebraska was not noted until the spring of 1954, the source of the mites infesting the winter wheat crop in the fall of 1953 was not sought and remains unknown. It is possible that such mites were wind-borne into the winter wheat crop from occasional scattered stands of volunteer wheat on which the mites survived from wheat harvest in the summer of 1953 until wheat was again planted in the fall. Such isolated patches of volunteer wheat supplying foci of infestation and infection could easily have been overlooked in the fall survey of winter wheat fields since volunteer wheat is not common in eastern Nebraska.

Viruliferous mites may have been transported from various native grasses into the winter wheat crop. The grass species composition in eastern Nebraska is radically different from that in western Nebraska. Those grass species on which *A. tulipae* can survive in western Nebraska are rare in eastern Nebraska and no grass species is known to be common in eastern Nebraska on which *A. tulipae* can multiply. Samples of annual and perennial grasses were collected along the margins of diseased wheat fields in eastern Nebraska in the spring of 1954 but no mites were found on any of the grass species examined.

It is also possible that mites infesting the winter wheat crop originated in an area far removed from eastern Nebraska. Laboratory experiments have shown that *A. tulipae* may survive without food for 15 to 20 hours, time enough for these mites to be dispersed many miles by the wind. Pady (1955) states that *A. tulipae* was trapped from the air 1½ to 2 miles from the nearest wheat field.

## CONTROL MEASURES FOR WHEAT STREAK MOSAIC IN NEBRASKA

On the basis of these studies on the epidemiology of wheat streak mosaic, the following recommendations can be made for the control of this disease in western Nebraska.

1. *Destruction of volunteer wheat*

Volunteer wheat arising early, either before the normal time of harvest or shortly thereafter, is suspect as a source of viruliferous mites. Such volunteer wheat if mite-infested will display rolled and trapped leaves or even be infected to a certain extent with streak mosaic. The

early volunteer wheat should be destroyed at least two weeks before wheat is again planted. Volunteer wheat occurring late in the summer several weeks after the normal time of harvest is of little consequence and may be ignored.

2. *Late planting*

Generally, the later the wheat is planted, the less it is exposed to viruliferous mites in the fall. Therefore winter wheat should be planted as late as agronomic practices will allow. However, it must be borne in mind that the effectiveness of late planting is conditioned by the extent of warm weather in the fall. If high temperatures prevail long into the fall and early winter, even wheat planted at a very late date may suffer from wheat streak mosaic.

3. *Elimination of grasses other than wheat*

On the basis of the available evidence, the destruction of native perennial and annual grasses in the vicinity of wheat fields is not warranted. These grasses do not appear to be particularly important in the epidemiology of wheat streak mosaic. Under certain environmental conditions, particularly with the prolongation of warm weather in the fall, it is possible that viruliferous mites derived from native grasses may create minor epidemics in the wheat crop.

4. *The use of miticides on the winter wheat crop*

The use of miticides on the winter wheat crop in the fall is not feasible, owing to the limitations in effectiveness of the miticides themselves plus the difficulty in knowing when to apply them.

## SUMMARY

1. The salient details of the life cycle of *Aceria tulipae* at 24° to 27° C. are as follows:

| | |
|---|---|
| Complete cycle from egg to egg | 8 to 10 days |
| Egg incubation period | 3 days |
| First nymph | 1½ days |
| First molt | ¾ day |
| Second nymph | 1½ days |
| Second molt | ¾ day |
| Egg hatching to adult | 4 to 5 days |
| Preoviposition period | 1 to 2 days |

2. Reproduction of *A. tulipae* occurs parthenogenetically and an average of at least 12 eggs is laid by each female.

3. Observation in and out of the epidemic area in Kimball County plus information acquired from field tests in which volunteer wheat was simulated indicate that early volunteer wheat, germinating either before or immediately after harvest, is important in the epidemiology of wheat streak mosaic. It is postulated that under such conditions, a continuity of suitable food plants is provided favoring large increases in mites and virus during the summer months. The continuity of favorable food plants is interrupted when volunteer wheat emerges several weeks after harvest and such wheat is not particularly important in the epidemiology of this disease in western Nebraska.

4. Hail storms occurring before harvest at a time when the kernels are able to germinate but the crop is still somewhat green, are important factors in the epidemiology of wheat streak mosaic in western Nebraska.

5. The importance of wind as the main method of mite dispersal was emphasized by trap collections from the epidemic area of Kimball County in the fall of 1953.

6. An analysis of trapping data correlated with certain environmental factors indicated that the incidence of wheat streak mosaic in any winter wheat field in the epidemic area of Kimball County was associated with the distance the winter wheat field was removed from infested and infected volunteer wheat, the amount of inoculum and the degree of mite infestation in the volunteer wheat, and the condition of the volunteer wheat.

7. Prolonged high fall temperatures increase the period of exposure of the winter wheat crop to viruliferous mites.

8. Trap collections made in December and January suggest that *A. tulipae* may be wind-borne during warm periods in the winter and that therefore mite migration may occur throughout the year. It ap-

pears, however, that mite dispersal during the winter is of little importance in the epidemiology of wheat streak mosaic.

9. A significant correlation was found between mite dispersal and estimated wind velocity. Mite dispersal was not correlated with maximum, minimum or mean daily temperatures.

10. Wheat streak mosaic infection appeared to be a predisposing factor in winterkilling of the wheat crop in the epidemic area of Kimball County during the winter of 1953-54.

11. Experimentally it was shown that infection occurring early in the development of wheat plants is most damaging. This implies that spring infection in winter wheat is not of much consequence, that wheat arising early in the fall and soon infected is seriously damaged and that wheat infected a considerable time after emergence is not injured to the same extent.

12. Data from a date of planting experiment demonstrate that disease incidence is correlated with date of planting. Wheat planted early in the fall is exposed to greater numbers of viruliferous mites than wheat planted later in the fall.

13. A survey of native annual and perennial grasses for *A. tulipae* was made in western Nebraska during the summer of 1954. No species of annual grass was encountered that was a favorable host for this mite. Western wheatgrass, *Agropyron smithii* Rydb., Canada wild rye, *Elymus canadensis* L., Indian rice grass, *Oryzopsis hymenoides* (R. & S.) Ricker, and Wheeler's bluegrass, *Poa nervosa* (Hook.) Vasey, were found to be hosts on which *A. tulipae* can multiply.

14. Judging from the evidence available, annual and perennial grasses do not appear to be important in the epidemiology of wheat streak mosaic in western Nebraska.

15. Under the conditions existing in the epidemic area of Kimball County in 1953, single applications of systox and parathion on September 12 were ineffectual in reducing the incidence of wheat streak mosaic. The use of miticides on the winter wheat crop in the fall is not considered feasible.

16. An appraisal of the minor wheat streak mosaic epidemic in eastern Nebraska in 1954 indicates that factors responsible in the epidemiology of this disease in eastern Nebraska may differ from those of importance in western Nebraska.

17. Wheat streak mosaic may be mitigated in western Nebraska by late planting and the elimination of volunteer wheat appearing shortly before or after harvest. The destruction of native grasses and the application of miticides to the winter wheat crop in the fall are not important or practical in the control of this disease.

## LITERATURE CITED


CONNIN, R. V.

1956. The Host Range of the Wheat Curl Mite, Vector of Wheat Streak Mosaic. Jour. Econ. Ent. Vol. 49: 1-4.

HASKELL, R. J. AND WOOD, J. I.

1923. Diseases of Cereal and Forage Crops in the United States in 1922. U.S.D.A., Bur. Plant Indus. Plant Disease Bul. Sup. 27: 164-226.

KEIFER, H. H.

1938. Eriophyid Studies. Calif. Dept. Agr. Bul. 27: 181-206.

KEIFER, H. H.

1952. The Eriophyid Mites of California (Acarina: Eriophyidae). Bull. of the Calif. Insect Survey Vol. 2, No. 1.

MCKINNEY, H. H.

1930. A Mosaic of Wheat Transmissible to All Cereal Species in the Tribe Hordeae. Jour. Agr. Res. 40: 547-556.

MCKINNEY, H. H.

1937. Mosaic Diseases of Wheat and Related Cereals. U.S.D.A. Circ. 442: 1-22.

MCKINNEY, H. H. AND FELLOWS, HURLEY

1951. Wild and Forage Grasses Found to be Susceptible to the Wheat Streak-Mosaic Virus. Pl. Dis. Rept. 35: No. 10. 441-442.

PADY, S. M.

1955. The Occurrence of the Vector of Wheat Streak Mosaic, *Aceria tulipae,* on Slides Exposed in the Air. Pl. Dis. Rept. 39: No. 4. 296-297.

PAINTER, R. H. AND SCHESSER, JOHN

1954. Western Wheat Grass, an Over-Summering Host of *Aceria tulipae* (K.), Vector of Streak-Mosaic of Wheat. Jour. Kansas Ent. Soc. 27: 118-119.

SILL, W. H. JR. AND CONNIN, R. V.

1953. Summary of the Known Host Range of the Wheat Streak Mosaic Virus. Trans. Kansas Acad. Sci. 56: 411-417.

SLYKHUIS, J. T.

1952. Virus Diseases of Cereal Crops in South Dakota. S. D. Agr. Expt. Sta. Tech. Bul. 11: 1-29.

SLYKHUIS, J. T.

1953. Wheat Streak Mosaic in Alberta and Factors Related to its Spread. Can. Jour. Agr. Sci. 33: 195-197.

SLYKHUIS, J. T.

1955. *Aceria tulipae* Keifer (Acarina: Eriophyidae) in Relation to the Spread of Wheat Streak Mosaic. Phytopath. 45: 116-128.


3M