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The Wheat Curl Mite, *Aceria tulipae* Keifer, in Relation to Epidemiology and Control of Wheat Streak Mosaic

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The Wheat Curl Mite, *Aceria tulipae* Keifer, in Relation to Epidemiology and Control of Wheat Streak Mosaic[1]

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INTRODUCTION

Wheat streak mosaic is a serious disease of wheat in Kansas, other Great Plains states, and Canada. Research has been conducted since 1949 on the disease and its possible vectors. Continuous study of epidemiology has led to a gradual understanding of relationships among vectors, hosts, agronomic practices, and weather. This bulletin presents extensive data on native grass hosts of the mite vector, seasonal development of mites in volunteer and planted wheat, and methods to determine mite infestations in the field. It also summarizes previous work and explains why recommended control practices are effective.

THE WHEAT CURL MITE

The wheat curl mite, *Aceria tulipae* Keifer, was reported as the vector of wheat streak mosaic virus (WSMV) by Slykhuis (195 3) . Other mites and insects have been studied as possible vectors, but the wheat curl mite is the only known vector (Atkinson 1953, Connin & Staples 1957, del Rosario & Sill 1965). Spread by abrasive leaf action during high winds (Sill 1953b) is minor. Keifer (1938) described the wheat curl mite as an eriophyid mite found primarily on tulips and onions and occasionally on grasses. Now several strains of the mite (del Rosario & Sill 1965) are known; some are found typically on grasses. Occasionally they also are found on Liliaceous plants (Keifer 1938). However, its primary hosts are wheat and various grasses.

The many species of Aceria and other closely related genera require microscopic examination for identification. Inability of workers to identify the mites quickly and accurately delays ecological and biological studies and makes predicting virus epiphytotics much more difficult.

Mite as Vector of Disease

A. tulipae is an efficient vector of WSMV. Staples and Allington (1956) and del Rosario (1959) reported transmission efficiency as high as 84-92%. However, even closely related species of eriophyid mites do not transmit the virus (del Rosario and Sill 1965). All stages of the mite, except the egg, can transmit the virus (Slykhuis 1955, del Rosario 1957, del Rosario & Sill 1958), but only nymphs can acquire it. The virus is persistent in *A. tulipae*. The mite was shown to be viruliferous for

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as long as 21 days after feeding on infected plants (del Rosario & Sill 1958, 1965).

Reproductive Potential of Mite

In a favorable environment the wheat curl mite completes a life cycle in 8 to 10 days. Each mite is capable of laying at least 12 eggs (Staples and Allington 1956) and sometimes 20 (del Rosario & Sill, 1958). Thus, under ideal conditions, each mite conceivably could have over 3 million descendants in 60 days. Not all the mites would survive, of course, nor would they all be viruliferous.

Dispersal of Mite

Wind plays a major role in mite dispersal and a windbreak offers no barrier to its dispersal (Pady 1955, Slykhuis 1955, Staples & Allington 1956). We have found mite infestations higher on the downwind side of a windbreak, possibly because lower wind velocity there permits them to drop from the wind current. Gibson (1957b) reported that mites can hitchhike on legs and bodies of aphids, and del Rosario (1959) and del Rosario and Sill (1958) reported that mites can walk from 4 to 5 cm. per hour on a smoked glass slide. Probably neither method of dispersal is important when compared with wind. Gibson (1957a) showed that mites can move directly from infested germinating wheat seeds into new seedlings, particularly after nearly mature grain is shattered during hail storms. However, virus is not transferred from plant to plant under those conditions (Gibson 1957a, Staples & Allington 1956).

Effect of Environmental Factors on Mite Reproduction

Wheat curl mites can withstand extremely cold temperatures, and a few warm days during the winter will cause them to become active. Infested wheat plants can be brought from the field any time during the coldest winter, and adults, nymphs, and eggs can be found. The adults and nymphs become active in a few minutes at room temperature, and eggs hatch in a day or two. Slykhuis (1955) found that under laboratory conditions Yogo wheat did not survive at -15°C and -20°C, yet mites survived for 2 days and eggs survived for 8 days. Later, del Rosario (1959) showed that mites could survive near-freezing temperatures for three months.

Slykhuis (1955) found that at high temperatures the mites survived best at high humidities. At 25° C survival was best at 100% humidity and intermediate at 75%; at 25% relative humidity no mites survived.

Mites are sensitive to temperature changes during reproduction. del Rosario (1959) and del Rosario and Sill (1958) found that mite populations increased rapidly at 24°C, only slowly at 7°C and not at all at 0°C.

We found that during the summer months frequent rains and cooler-than-average temperatures favor mite increase and survival, while high temperatures with below normal or infrequent rains decrease mite populations. Disease-loss records in Nebraska (Staples & Allington 1956) and Kansas were compared with official weather records to determine possible correlations between climatic factors and disease incidence and losses. The study covered 11 years, 1948-1959. The climatic pattern for severe crop-loss years (1948-49, 1950-51, 1953-54, and 1958-59) indicates that during the critical months from July through November near or above normal rainfall was related to severe damage by WSMV. Near or below normal July and August temperatures combined with above normal September, October, and November temperatures also increase possibilities of a severely-infected wheat crop. High or reasonably high humidities favor the mites. Nebraska's severe mosaic loss in 1953-54 was under such conditions.

Identification and Preservation of Mites

The wheat curl mite is about 250 microns long and 75 microns wide (Keifer 1938, 1952). It is almost impossible to see without magnification, and a 20X lens is necessary for field identification. Even then accurate identification of genus cannot be made. Research workers must often rely on plant symptoms to indicate presence of mites. Symptoms on wheat and grass seedlings are usually reliable. On older plants, symptoms are more difficult to detect, so a thorough knowledge of susceptible host plants is needed to determine presence of wheat curl mites or WSMV.

Often during our investigation single mites or very small colonies were found. Identification of such mites was difficult and often impossible in the field. Consequently, a method was developed to collect and preserve them for later study (Somsen, 1966).

Wheat Curl Mite on Wheat

When a mite falls upon a wheat plant, its favorite host, it immediately migrates down into the moist, succulent base of the leaf sheath. As the leaf grows, the section where the mite is feeding is pushed upward. As the leaf unrolls from the center, a small spot remains curled where the mites are feeding--the first symptom that mites are present. The mites do not roll or curl the leaf but merely prevent it from unrolling. A microscopic examination inside the roll will usually show eggs and nymphs. Mature mites usually die or migrate down into the sheath. After mite populations become quite large, entire lengths of leaves are rolled, and the tip of the next emerging leaf may become trapped. Rolling makes infested leaves more rigid than normal so they stand high in the field, and often can be seen several feet away. Trace mite infestations can be determined accurately by quickly scanning hundreds of leaves in the field. That is faster than closely examining 15 or 20 leaves under a laboratory microscope. Light infestations rapidly become heavy if environmental conditions are right (Slykhuis 1952, del Rosario & Sill 1965). It is therefore important to find trace infestations in surveys. Light infestations on older plants are often more difficult to find owing to increased foliage and somewhat more rigid leaves. However, careful examination will detect the same leaf rolling found in younger plants.

Season and ecological situation

greatly affect mite populations. A brief outline of the seasons and locations most favorable for mites in planted or volunteer wheat follows.

Mid-June to Mid-July

Volunteer wheat developing just before, during, or immediately after harvest is the prime source of mites from mid-June to mid-July. Very small volunteer wheat often is present and infested during that period, particularly when harvests have been prolonged by a rainy period or when the wheat has started to grow after hail or rain shattered it before harvest (Staples & Allington 1956). Such volunteer wheat that has been growing from 6 to 8 weeks is most likely to harbor mites. Several locations should be checked carefully during this period: corners of fields where the grain combines left heavy clumps of straw, areas along roads or trails in fields where grain was transferred from combine to truck, and low areas in fields where trucks and harvesting equipment may have become mired or cut deep ruts. Wheat scattered in moist, well-protected spots grows throughout the summer even in dry years. Such spots are also good places to find other mites, insects, and wheat diseases.

Mid-July to Mid-August

Small, emerging volunteer is not likely to be infested from mid-July to mid-August unless a source of mites is nearby, as in volunteer wheat or various grasses. Large volunteer wheat will usually be infested and should be destroyed. It should be saved for pasture only if disease and mite free.

Mid-August to Mid-September

Mid-August to mid-September, when large volunteer wheat often is infested with mites and infected with virus, is most critical in development of wheat curl mite populations and wheat streak mosaic. Medium-to-small volunteer wheat usually will not contain many mites if there were no green wheat plants immediately after harvest. A thorough search is necessary at this time to evaluate the effect of volunteer wheat on an epiphytotic of streak mosaic. As a general precautionary measure, it is advisable to destroy old volunteer wheat, which usually does not produce much pasture during this period because of streak mosaic and other diseases and insects. Not much wheat is planted during this early fall period because it is exposed to early mite infestation, virus infection, heat and drought.

Mid-September to Mid-October

Mid-September to mid-October is the normal wheat planting period for most of Kansas. It also is when many fields of old volunteer wheat are deteriorating from drought and disease--and mites are actively migrating from fields and being dispersed by wind over a wide area. During wet years when there is some delay in destroying volunteer wheat, large areas of planted wheat may become infested. Greatest loss from WSMV has been when early-planted wheat fields were placed between those of old volunteer. In states where both spring and winter wheats are grown, severe loss has occurred when spring wheat harvest overlapped winter wheat planting (Atkinson & Slykhuis 1963).

Mid-October to March

Wheat planted after October 20 usually is free of virus infection (Staples & Allington 1956, Slykhuis 1952, Connin 1956a). Even when an unusually warm fall allows mites to build up, mosaic is seldom a problem in Kansas when wheat is planted after October 1. Winter wheat may become infected in the spring but usually not until the plants are jointing. By then typical mature plant resistance has developed so there is little loss from virus infection.

April to Mid-June

During April, May, and June a few mites can be found in almost all fields, usually in low spots, behind hedge rows, or other protected places. As the season progresses, if environmental conditions are satisfactory, mite populations increase. As the wheat plants near maturity, it is common to find every wheat head in a field infested with mites. This may be true even though no mosaic symptoms appear, because mites often are nonviruliferous. Hundreds of mites may be present on a single wheat head, with no apparent damage. Such mites die or leave the plant as the wheat ripens. Only a very small percentage of those leaving the plant survive to become established on a new host plant.

The role of volunteer wheat in epidemiology discussed here also has been studied by others (Connin 1956a, Gibson 1957b, Slykhuis 1955, Staples & Allington 1956). In summary, field observations show that volunteer wheat emerging at or shortly after harvest provides an excellent host for oversummering mites Staples and Allington (1956) showed that early volunteer wheat, following hail or lodging, soon can become infested with mites and infected with virus. Then when fall planted wheat appears, viruliferous mites readily moved from volunteer to planted wheat (Connin 1956, and Slykhuis 1952). Volunteer wheat is the major source of both mites and virus for fall planted wheat, but mites and WSMV use many other host plants for survival.

Wheat Curl Mites on Corn, Sorghum and Millet

Several varieties of corn are susceptible both to the mite and WSMV under greenhouse conditions (Sill & Agusiobo 1955, Finley 1957, Sill & del Rosario 1959). However, we have only rarely observed mites on corn under field conditions. In one case an entire ear of corn had become buried and all the kernels had sprouted at once in early summer. Three or four of the crowded and spindly seedlings contained large colonies of mites and eggs. Although no large field infestations of the mites have been found on corn in Kansas, corn has been reported to be an important host for the mite in Ohio and Iowa (Ford & Lambe, 1966; McKinney et al., 1966). Greenhouse observation shows that very young corn plants exhibit the characteristic rolling and trapping of leaves (Sill & del Rosario 1959), but older plants do not. Mites usually colonize in the leaf whorl so only careful plant dissection and microscopic examination will reveal them. Finding small colonies of mites or single individuals on large corn plants is exceedingly difficult.

Occasional reports are made of mites on seedling sorghum plants in the greenhouse or in experimental plots. Gibson (1957a) reported mites on sorghum for as long as 26 days under experimental field conditions. There are no reports of mites in planted fields of sorghum. Between 1957-1963, we examined many sorghum fields without finding mites. In many cases weed grasses in the field were infested, showing that the sorghum had been exposed to the mite. Sorghum is not an important host for oversummering mites; it is also immune to the virus.

Sill and Agusiobo (1955) tested 17 millet accessions for susceptibility to WSMV. Reactions varied from susceptible to immune. Slykhuis (1953) and Atkinson (1953) studied millet with similar results. Some commonly grown millets, particularly proso millet, were susceptible. Susceptible millets, if increased in Kansas, could be important oversummering hosts. Several times in 1954 and 1955 we saw millet fields in Kansas severely infested with mites and infected with virus. They could have served as an important source of infection for wheat. Similar reports have been made in Nebraska. However, millet is a minor field crop and, hence, cannot be considered important in WSMV epidemiology in Kansas. In the few fields observed since 1956, no mites or mosaic was found.

Accumulated evidence indicates that corn, sorghum, and millets are not important hosts of the virus or mites in Kansas.

Mites on Rye

Rye, a winter annual like wheat, is susceptible both to mites and WSMV (Slykhuis, 1952). For the 1966-67 crop year 203,000 acres of rye were planted in Kansas; 57,000 acres were harvested with the remainder used for pasture. Virus infection of rye is common, but no major mite infestations of rye have been found during the normal crop season. Large vigorous colonies have been found in volunteer rye during summers. Volunteer rye is often infested with the virus, so it is considered important in developing local WSMV epiphytotics.

Mites on Barley

Barley is susceptible both to the virus and the mite, and infections and infestations are common. Sill, Bellingham, and Fellows (1964) tested several commercial varieties of barley for reaction to the virus. All were systemically infected, but not appreciably damaged under field conditions. Wheat streak mosaic is not considered a limiting factor in barley production.

Barley would be important in epidemiology if larger acreages were grown, but only 119,000 acres of barley were seed in Kansas in 1967, about three-fourths of winter barley varieties.

Mites on Cultivated Oats

The oat crop is of minor importance in epidemiology. It is susceptible both to virus and mites (Slykhuis 1955) but not damaged by them. Oats acreage is small (218,000 acres in 1966-67), and is decreasing in Kansas. The biggest acreage remaining is in eastern Kansas where WSMV has never been an important problem. Most of the oat crop is spring sown, but farmers in some southern border counties plant small amounts of winter oats.

Mites on Native Grasses

Some native grasses are of major importance in survival of mites and virus, particularly when seeded or when volunteer plants of cultivated crops are sparse or absent. Many grasses are infected under natural conditions and help spread the virus. Their importance is in their growth characteristics, especially the perennials, by surviving through dry periods, and serving as possible hosts for both mites and virus until conditions become favorable for volunteer wheat or other susceptible grains. The relative importance of any species of grass depends on its susceptibility to mites and virus, its habit of growth, its distribution, and abundance. Using those criteria, we classified grasses we studied according to their probable importance in WSMV epidemiology (Table 1). All data concerning the distribution of the grasses are taken from Gates (1936), where the grasses are discussed in detail. Nomenclature follows Anderson and Owensby (1969).

Grasses are much more difficult than wheat to examine for mites. Seedling grasses in the 2- to 4-leaf stage show about the same plant symptoms from mite infestation as does wheat, but as grasses mature, particularly the perennial ones, foliage becomes more rigid and symptoms less prominent. The youngest and tenderest seedlings of grasses should be examined first, as should tender succulent portions of older plants. The area just above and be low the ligule is a likely spot for mites.

Types of mite infestations vary. When mites are abundant on wheat a single mite or very small colonies on a grass may mean little in epidemiology. A small colony can be the progeny of a single mite that existed a short time on an unfavorable host. Two or three adult mites without eggs or with immature form present may mean they are unable to reproduce on a particular grass. del Rosario and Sill (1965) found some physiological strains of mites took considerable time to adapt to a new host. Somsen (1966) reported active migratory forms readily moving from one host to another and at times on quite unfavorable host plants. Mites that come from wheat and infested seedling grasses may revert to wheat easily, whereas mites coming from old stands of grass may be adapted exclusively to that grass. All such facts are needed to avoid erroneous conclusions. To be sure that a plant is susceptible, one must observe a mite colony showing a full reproductive cycle.

We examined collections of mites from many grasses (Table 1). Identification was often made in the field and therefore was not always accurate. For example, mites on new stands of western wheat-grass, (*Agropyron smithii* L.) were usually *A. tulipae*, while colonies found on old well-established stands of that grass were often another species.

Various grasses, in alphabetical order by genus, are discussed here.

Scientific names are usually used because common names vary. Relative terms like “fair,” “good,” or “abundant” are used because exact numbers of mites are not available.

Aegilops cylindrica Host, jointed goatgrass.--We found this grass infected naturally with the virus, as have others (Connin 1956b, McKinney & Fellows 1951, Sill & Connin 1953). Mites reproduce ‘‘fair” to “good” on the grass (Connin 1956b) and have been collected on it in several central Kansas counties. Goatgrass, susceptible to the virus in the greenhouse (Connin 1956b, McKinney & Fellows 1951, Sill & Connin 1953), is an annual that can be important during early summer in perpetuating both mites and virus. However, its short growth period somewhat decreases its significance. It is usually ripe and dry by the time wheat matures, so it can function as a host only during early summer. Although collected in only 23 Kansas counties (Gates 1936)[4], mostly in central Kansas, it undoubtedly exists in many more counties and is spreading throughout the state. In counties where collected, it was considered an “abundant” grass in cultivated fields and along roadways.

Agropyron repens (L.) Beauv., quackgrass.--Quackgrass has been found infested with mites during the critical July and August period. Although it is one of the most susceptible of the Agropyrons to mite infestation, it is immune to the virus (Sill & Connin 1953, Slykhuis 1952). Its limited distribution in Kansas keeps it from being considered an important mite host.

Agropyron smithii Rydb., western wheatgrass.--This is believed to be the most important native, perennial grass studied as a host of the wheat curl mite. It is widely distributed in Kansas, is green and succulent during the critical summer period, and is common along field borders and roadsides. Three species of eriophyid mites in addition to the wheat curl mite have been found on it. They are *Aceria agropyronis* (Keifer), *A. slykhuisi* (Hall), and *Aculus mckenziei* (Keifer) (Daniels 1963). Because of the difficulty of accurate field identification of mites, reports of *Aceria tulipae* (Keifer) on this and other grasses may be in error. Since western wheatgrass is immune to WSMV infection, mites must first transfer from it to some diseased plant and transfer again to the planted wheat crop to spread the disease to wheat. Strains of *A. tulipae* (Keifer) that are adapted to western wheatgrass but adapt to wheat with difficulty (del Rosario & Sill 1965) complicate the situation further. This grass is important in maintaining constant mite infestations in any area, but because of its virus immunity, it is not directly capable of producing viruliferous mites for infecting wheat. Several times field evidence has indicated that infestations of mites in seedling wheat have spread directly from this grass. As might be expected, mosaic was not present in any of those instances.

Bouteloua hirsuta Lag., hairy grama.--This grass is a host of major importance because mites reproduce

4. The distribution and abundance of grasses are based on (Gates 1936).

well on it and it is susceptible to the virus (Sill & Agusiobo 1955, Connin 1956). It is "abundant" in most of Kansas. It is a perennial grass and not only provides an oversummering host for the mites and the virus but also perpetuates both from year-to-year, especially during adverse conditions.

Bromus japonicus Thunb., Japanese brome.--Japanese brome was reported by McKinney and Fellows (1951) as infected with WSMV in the field, which we often confirmed. *B. japonicus* is an "abundant" grass in all areas except extreme southwestern Kansas. As a winter annual, it may be important in epidemiology, particularly in spring and early summer. It often becomes infested with mites in the spring when they leave ripening wheat. Because this grass matures so early in the summer, it cannot serve as a complete over-summering bridge either for the mites or the virus. It probably serves as an important, but temporary, host for both.

Bromus secalinus L., cheat.--Cheat is an annual grass, present from April to August, abundant in eastern Kansas. It is "moderately" susceptible to mites in the greenhouse and small numbers have been found in field collections. It is susceptible to the virus (Slykhuis 1952, Sill & Connin 1953) and we often found field infections of it. It is a common grass in stubble fields so it may serve as a bridge for both virus and mites during the summer until volunteer wheat is available.

Bromus tectorum L., downy brome. --This grass often has been found infected with WSMV in the field (Sill & Connin 1953). It is an "abundant" annual in western Kansas. Connin (1956) reported no mite reproduction, but the senior author has often observed small colonies of the mites on young seedlings and frequently on nearly mature heads. Since large mite populations do not develop on this grass, its importance in epidemiology probably is minimal.

Buchloe dactyloides (Nutt.) Engelm., buffalograss.--This grass is found in central and western Kansas and is dominant in many pastures. In the greenhouse mites persist on it, but reproduction is slow. Several field collections of mites have been made from it, particularly when mites were abundant on wheat. Most were *A. tulipae*, but some were *A. slykhuisi* (Hall 1958). Buffalograss is common along roadsides adjacent to wheat fields and has many opportunities to become infested. However, the grass is immune to WSMV (Sill & Agusiobo 1955), so probably is not important in epidemiology.

Cenchrus pauciflorus Benth., sandbur.--This grass is an "abundant" grass in most of the state, particularly in sandy locations. Sill and Connin (1956) reported "good" mite reproduction, noting that the grass is often a symptomless carrier of the virus. We also found mites on this grass. Staples and Allington (1956) reported that sandbur in nature was not a host of the mite.

It is generally agreed (Connin 1956b, Hasket et al. 1956, Harvey 1951) that the stage of maturity of a grass species may influence its susceptibility as a host of both mites and virus. Young sandbur may be important in spreading the virus, but as the grass matures it may become less important. However, mites often have been found by the senior author on the few remaining green leaves of this grass when nearly ripe burrs appeared. Possibly, mites travel from field to field on the burrs as they are moved about by wind or animals. This grass may be more important in epidemiology than previously thought.

Cynodon dactylon (L.) Pers., bermudagrass.--This grass is common in eastern Kansas. Mites colonize well on it in the greenhouse, but few have been found in the field. It is a warm season grass, developing late in the spring, often not growing vigorously until July. It is present during the summer when volunteer wheat is usually scarce. Although susceptible to the virus in the greenhouse, it has never been found infected in the field. Tuttle and Butler (1961) reported that two species of Aceria other than *A. tulipae* (Keifer) infest bermudagrass in California. Since mite identification is difficult, earlier identifications of *A. tulipae* (Keifer) on it may have been wrong. It probably is not important in WSMV epidemiology in Kansas.

Digitaria sanguinalis (L.) Scop., crabgrass, and *Digitaria ischaemum* (Schreb) , smooth crabgrass.--The crabgrasses are “abundant” and widely distributed annuals in Kansas. They are found infected with the virus frequently in nature and are easily infected in the greenhouse (Sill & Connin 1953). Connin 1956b) reported that mites reproduce “very poorly” on crabgrasses, but we found them to be “good” mite hosts. Our records list mite collections from crabgrass in 16 Kansas counties. *D. sanguinalis* is commoner than *D. ischaemum*, but field reports do not distinguish between the two. They are warm weather grasses, reach peak growth in late summer, and mature early in the fall. As they die in the fall, mites are forced to move to other hosts, usually late in September or October when many wheat plants have emerged and are still young and succulent. Mites moving from crabgrasses to wheat could carry the virus, so the grasses may be important in local epidemiology.

Echinochloa crusgalli (L.) Beauv., barnyardgrass.--This is an annual found naturally infested with the virus in the field (Sill & Connin 1953). It is a “good” host for both mites and mosaic in the greenhouse and small numbers of mites and eggs have been found on it under natural conditions. Barnyardgrass is a common weed grass and is considered important because of its abundance in wheat fields.

Elymus canadensis L., Canada wildrye.--Canada wildrye is “abundant” in most of Kansas. It is a sturdy perennial so may be an important means of perpetuating the virus and mites during adverse conditions. The virus is often found on this grass in nature (McKinney & Fellows 1951, Sill & Connin 1953), and it may be one of the original native hosts in the Great Plains. Slykhuis was unable to obtain mite survival on this grass and suggested that a strain difference in the mite *A. tulipae* might account for the problem. Connin (1956b), however, was able to transfer mites without difficulty from wheat to

Canada wildrye and back to wheat. While on Canada wildrye the mites had a "fair" reproductive rate. Apparently, the grass never carries large numbers of mites, but some usually are found, and they have been collected often in north-central Kansas.

Elymus virginicus L., Virginia wildrye.--This grass is also a perennial but not so common as Canada wildrye in Kansas. It also serves as a year-to-year means of perpetuating the virus and mites through adverse conditions. Although the grass seldom contains large numbers of mites, it often was found naturally infected with the virus in the field, by Sill and Connin (1953), and by Sill during 1955 to 1962.

Eragrostis cilianensis (All.) Lutati, stinkgrass.--This grass is a "good" virus host. Mite infestations are common on it in the field. It is widespread and "abundant" throughout Kansas and is at its most susceptible stage for both mites and virus when mites are migrating from ripening wheat heads. It remains green through the summer, but becomes less favorable as a mite host as it matures. At wheat planting time it is usually free of mites. It is particularly important as a host for virus and mites between wheat harvest and emergence of volunteer wheat in mid and late summer. It is probably important in WSMV epidemiology.

Hordeum pusillum Nutt., little barley.--This grass is a common roadside weed throughout Kansas. Mites are quite common on it early in the season. Little barley is usually ripe before winter wheat is, so it will maintain mites for a short while, but is not important as a host even during the early summer. It is immune to WSMV.

Panicum capillare L., common witchgrass.--This is an "abundant" annual grass throughout the state, especially common in stubble fields. Connin (1956b) reported no mite reproduction on it in the laboratory, but he found it naturally infected with WSMV in the field (Sill & Connin, 1953). Mites are able to feed on it although they may not reproduce. Grasses like *P. capillare* probably serve as a temporary stopping place for mites and also as an occasional source of virus for wheat, when viruliferous mites are blown to wheat from the grass. Because of its abundance, it is considered important in epidemiology.

Setaria lutescens (Weigel) Hubb., yellow bristlegrass or foxtail.--This is a relatively common grass and will support small populations of the mite, but it is immune to the virus (Sill & Connin 1953). It remains green most of the summer and at times serves as a source of mites for early volunteer wheat but probably is of minor epidemiological significance.

Setaria viridis (L.) Beauv., green bristlegrass or foxtail.--This grass was first found naturally infected with WSMV by Fellows (Sill & Connin 1953). It was reported susceptible in greenhouse experiments by Slykhuis (1951). It is probably the most frequent WSMV-infected grass in Kansas. Because of its wide distribution, it is important in epidemiology. Connin (1956) found that mites reproduced well on it, and we have often found mites on it in the field. Since it grows from July to September in Kansas, it is young when wheat is harvested and ready for invasion by the mites. It provides a good host for buildup of both mites and virus during the most critical period of the summer.

GRASSES AS HOSTS FOR WHEAT STREAK MOSAIC VIRUS

During our study we tested many grasses for their reaction to the virus, using the carborundum-inoculation method developed by McKinney and Fellows (1951). Four species of grass not previously tested were found to be susceptible (Borgman 1959). They are *Sitanion hystrix* (Nutt.) J. G. Smith, bottlebrush squirreltail; *Sporobolus neglectus* Nash, puffsheath dropseed; *S. airoides* (Torr.), alkali sacaton; and *S. cryptandrus* (Torr.), A. Gray, sand dropseed. The latter two species of *Sporobolus* are symptomless carriers of the virus.

Most of our inoculations confirm reports of others (Bellingham 1954, Sill & Connin 1953, Slykhuis 1955, Staples & Allington 1956, Sill & Agusiobo 1955). Our data, as well as mosaic reactions reported in the literature, are summarized in the table. Table 1 lists 16 species of grasses as probably important in the epidemiology of WSMV. That does not mean they are always important in epiphytotics. Most who have studied the problem agree that grasses normally keep the disease endemic in a given locality. Only large populations of mites and extensive presence of virus developing in volunteer or planted wheat has caused a widespread epiphytotic of the disease in Kansas. Earlier it was thought that WSMV was exclusively a disease of small grains and grasses, but it also is now known to be a disease of corn (Finley 1957, Sill & del Rosario 1959, Ford & Lambe 1967, McKinney et al. 1966).

Symptoms of WSMV on Various Grains and Grasses

Symptoms of WSMV vary tremendously on different grains and grasses. There are symptomless carriers, local lesion hosts, and many variations in symptom patterns in plants that show systemic symptoms. The various symptoms have been described elsewhere (McKinney 1937, McKinney 1944, McKinney & Fellows 1951, Slykhuis 1951, Slykhuis 1952, Fellows & Schmidt 1953, Sill & Connin 1953, Slykhuis 1953, Pady et al. 1955, Sill & Agusiobo 1955, Schmidt et al. 1956, Staples & Allington 1956, Finley 1957, Lal 1957, Borgman 1959, Ashworth & Futrell 1961).

Symptoms also have been well described on wheat. They vary widely at different temperature (Sill & Fellows 1953), on different cultivars (Sill et al. 1964), with different environments (Sill 1953, Pady et al. 1955) and with different strains of the virus (McKinney 1937, Lal 1957, Lal et al. 1957, Sill 1959). In general, symptoms on wheat are a yellowish streaking and mottling of leaves, accompanied by various degrees of stunting. Symptoms and losses in diseased plants usually are more severe during hot, dry weather than during cool, moist weather. During dry weather diseased plants look drouthy sooner than healthy plants, owing to greatly reduced root length and numbers (Sill 1959) and probably also because of secondary invasion by several soil fungi that cause roots to deteriorate.

CONTROL OF WHEAT STREAK MOSAIC

The severe losses caused in the past by widespread epiphytotics of WSMV can be reduced by applying three known methods of control.

DESTROYING VOLUNTEER WHEAT.--Clean cultivation at least two weeks before planting very effectively controls WSMV (Slykhuis 1955, Connin 1956a). It is important to destroy all plants infested with mites, as the mites cannot survive long away from green plants (del Rosario & Sill 1958). If possible this should include adjacent fields of volunteer wheat as well, particularly those upwind from the field to be planted (Staples & Allington 1956).

Because volunteer wheat is a valuable fall pasture, it should be checked to determine if it is carrying mites or virus before it is destroyed.

DELAYED PLANTING.--Planting at the latest possible recommended date is important and easily done. Several workers have shown that delayed planting of winter wheat reduces severity of the disease (Slykhuis 1952, Staples & Allington 1956, Slykhuis et al. 1957, Gibson 1957b). Disease incidence and severity are reduced because of reduced mite numbers and a general decrease in mite activity and reproduction as temperature drops in the fall (Gibson 1957b, del Rosario 1957, Briones 1967).

Unless the fall is unseasonably warm, October 1 is a safe planting date in Kansas. The safe fall planting date is later as one moves south into Oklahoma and Texas and is earlier in Nebraska, the Dakotas, and Canada. Slykhuis et al. (1957) reported it to be about September 5 in Alberta, Canada. If planting is delayed in Kansas until October 1, the wheat plants normally will not be large enough for mites until nearly November 1. By then mean temperatures usually are low enough to inactivate the mites for the winter.

RESISTANT CULTIVARS OF WHEAT.--An increasingly important control is resistant or tolerant cultivars (McKinney 1949, McKinney & Sando 1951, Andrews & Slykhuis 1956, Sill Bellingham & Fellows 1964). They were developed gradually, and even better cultivars are being developed. Currently recommended cultivars are Scout, Triumph, and Bison.

Thus far the resistance of wheat to WSMV has been weaker than desired, but even moderate resistance or field tolerance is very valuable in reducing losses.

OTHER TECHNIQUES RELATED TO CONTROL.--Collecting wheat plants randomly during fall and winter has helped predict prevalence of wheat streak mosaic (Fellows & Sill 1955). The plants are grown and observed in the greenhouse. Diseased plants will develop symptoms.

Another method of prediction, which we developed, also works well.

A general area survey is made for presence of mites. Because mites must be abundant and widespread to create epiphytotics of WSMV, examining many small but widely-spaced samples gives satisfactory results. Three to five well-spaced stops per county, plus an occasional examination of fields that appear to be volunteer or planted very early, make accurate predictions possible.

Examining rolled and trapped leaves, plus examining suspicious-appearing leaves with a 20X hand lens, is the fastest and most satisfactory method. Those unfamiliar with mite symptoms, or without equipment, may send samples to a laboratory for examination. They should be placed in plastic bags to keep them from drying out and to prevent mites from moving from sample to sample. The samples will keep for two or three days without refrigeration. When refrigerated, they will keep for a week or more, but examination becomes more difficult and less reliable the longer the samples are kept. Samples should consist of at least 20 to 30 tillers taken from 4 or 5 plants. It is unnecessary to keep soil on the roots.

After survey data are analyzed, a general pattern of mite infestation will be evident if mites are numerous enough to cause a widespread epiphytotic of WSMV. Also, a good source of the virus must also be present and the mites must be viruliferous or the epiphytotic will not develop.

If severe mite infestations are found in summer or fall in volunteer wheat, recommendations should be made to destroy the wheat.

SUMMARY

A thorough understanding of the epidemiology of wheat streak mosaic is important, because it is a major wheat disease throughout Kansas and the Great Plains.

The only known vector of the virus is the eriophyid mite, *Aceria tulipae* Keifer. It is an efficient wind-borne vector that reproduces rapidly under ideal conditions. If it is viruliferous, it continues to carry the virus so long as it lives.

Mites move deep into plants in cold weather and survive Kansas winters well. They do not reproduce rapidly until temperatures are well above 40°F. Hence, mite and virus movement is minimal during the late fall, winter, and early spring.

As temperatures rise in the spring, mites move from wheat sheaths or are moved from them as the leaves grow. They begin to lay eggs. Each mite can lay 12 to 20 eggs during an 8- to 10-day life cycle. During their rapid spring growth period, literally billions of mites can be blown from plant to plant. However, damage from spring virus spread is slight in Kansas. Winter wheat plants grow rapidly in early spring and become increasingly resistant as they mature. Consequently, they are not greatly damaged when infected by the virus.

As wheat matures, mites move to the ripening heads. They usually gather in large numbers in the green crease of the ripening grain or hang by anal suckers from the highest point of the plant-the tips of awns. They must migrate then or die on the maturing (dying) wheat.

During wheat harvest mites may be blown to young volunteer wheat plants, if they are available, or to suitable annual or perennial grasses. Lists of possible mite hosts, important in epidemiology, are included in Table 1.

To survive during summer, mites have suitable green or living plant hosts, mostly volunteer wheat, barley, oats, or grasses. The mites usually survive well and reproduce during cool periods when there is adequate moisture and relatively high humidity. They have difficulty surviving or reproducing when temperatures are high (100°F or above) and humidities low (50 % or less).

Grasses do not appear significant in developing large scale epiphytotics of mosaic, but are important in small local outbreaks and in preserving mites and virus during adverse conditions.

If moisture is adequate and temperatures cool, volunteer grain and grasses usually grow well and mite populations increase tremendously. If such a situation continues throughout summer into the fall, mites are typically present in huge numbers and many may be viruliferous if they are in an area where volunteer grain and susceptible perennial and annual grasses are infected with the virus. Without question, wheat, including volunteer, is the most important epidemiological host of both the virus and mite. If winter wheat is planted early when fall weather favors mite survival, reproduction and movement, then severe streak mosaic outbreaks may be expected.

However, if the summer, particularly late summer, has been hot and dry with little growth of volunteer grains or grasses, then typically few mites survive to damage the wheat crop. Thus, early planted wheat after a hot, dry summer usually is not much infected with virus.

Successful field control measures are based largely on knowledge of epidemiology. *First*, volunteer wheat (and other small grains) and grasses in and around fields to be planted must be destroyed at least 2 weeks before wheat is planted, as mites cannot survive except on living hosts. Clean cultivation must be maintained until the wheat is planted. *Second*, planting should be delayed to the latest recommended date for a given area so wheat may emerge as late as possible in the fall after mites have stopped moving, laying eggs, and hatching. This works well, except during unusually warm falls.

Those control measures are particularly effective when combined with a *third*, planting the most tolerant or resistant known cultivars recommended for a given area. Such cultivars change from year to year; information about them may be obtained from the Kansas Agricultural Experiment Station or county extension service office throughout the Great Plains.

Despite extensive efforts to control mites with various miticides, no effective chemical control has been found that also reduces virus incidence (Kantack & Knutson, 1954, 1958.)

Table 1.--Grasses examined in the field and/or laboratory and considered to be important in wheat streak mosaic epidemiology.

Scientific name	Common name	Field Examination % infested[1]	Laboratory reaction to Mites[2]	Laboratory reaction to WSMV[3]
Aegilops cylindrica Host	goatgrass	5.9	S	S
Agropyron smithii Rydb.	western wheatgrass	42.3	S	I
Bouteloua hirsuta Lag.	hairy grama	15.0	S	C
Bromus inermis Leyss.	smooth brome	6.2	S	I
Bromus tectorum L. and/or *Bromus japonicus* Thunb.	downy brome and/or Japanese brome	22.3	S	S
Bromus secalinus L.	cheat	7.7	S	S
Cenchrus pauciflorus Benth.	sandbur	3.4	S	S
Digitaria spp. Heister	crabgrass	3.6	S	S
Echinochloa crusgalli (L.) Beauv.	barnyardgrass	2.2	S	S
Elymus canadensis L.	Canada wildrye	1.4	S	S
Elymus virginicus L.	Virginia wildrye	20.0	S	S
Eragrostis cilianensis (All.) Lutati	stinkgrass	28.8	S	S
Panicum capillare L.	common witchgrass	1.4	S	S
Setaria lutescens (Weigel) Hubb.	yellow bristlegrass or foxtail	6.4	S	I
Setaria viridis (L.) Beauv.	green bristlegrass or foxtail	2.1	S	S

1. % of samples infested, each containing from 50 to 100 seedlings or culms.
2. S = Susceptible to mites.
3. S = Susceptible to wheat streak mosaic. I = Immune. C = Symptomless carrier of virus.

Table 2--Grasses examined in the field and/or laboratory and considered to be unimportant in epidemiology of wheat streak mosaic.

Scientific and common name of grass		Field Examination % infested[1]	Laboratory reaction to Mites[2]	WSMV[3]	Major reasons for not being considered important in epidemiology of wheat streak mosaic
Agropyron					
A. cristatum (L.) Gaertn.	fairway wheatgrass	.4	S	I	Limited distribution, poor mite host
A. elongatum (Hm) Beauv.	tall wheatgrass	35.4	S	I	Limited distribution, immunity to WSMV
A. repens (L.) Beauv.	quackgrass	10.3	S	I	Limited distribution, immunity to WSMV
A. trachycaulum (Link) Malte	slender wheatgrass	8.3	S	I	Limited distribution, immunity to WSMV
Andropogon					
A. gerardi Vitman	big bluestem	.2	S		Unfavorable as mite host
A. scoparius Michx	little bluestem	.0	R		Resistance to mites
Aristida.					
A. adscensionis L.	sixweeks threeawn	.0	R		Resists mites
Arrhenatherum					
A. elatius (L.) Presl	tall oatgrass	.0			Resists mites, limited distribution
Avena					
A. fatua L.	wild oat	.0	R	S	Limited distribution, resistance to mites
Beckmannia					
B. syzigachne (Steud.) Fernald	American sloughgrass	11.8	S	I	Limited distribution, immunity to WSMV
Bouteloua					
B. curtipendula (Michx.) Torr.	sideoats grama	.2	S	I	Absence of mites in field, immunity to WSMV
B. gracilis (H.B.K.) Lag. ex Steud.	blue grama	.0	S		Absence of mites in field
Buchloe					
B. dactyloides (Nutt.) Engelm.	buffalograss	3.4	S	I	Only small numbers of mites in field
Carex L.	sedge	.6	S	I	Immunity to WSMV, poor mite host

1. % of samples infested, each sample consisted of examining at least 50 seedlings, tillers, or culms unless mites were found sooner.
2. S = Susceptible, R = Resistant.
3. S = Susceptible, R = Resistant, C = Symptomless carrier of virus.

Table 2--Grasses examined in the field and/or laboratory and considered to be unimportant in epidemiology of wheat streak mosaic. (Continued)

Scientific and common name of grass		Field Examination % infested[1]	Laboratory reaction to Mites[2]	WSMV[3]	Major reasons for not being considered important in epidemiology of wheat streak mosaic
Cynodon					
C. dactylon (L.) Pers.	bermudagrass	2.6	S	S	Late season grass, does not become infested until after critical period.
Distichlis					
D. stricta (Torr.) Rydb.	inland saltgrass	2.2	S	S	Limited distribution of grass
Eleusine					
E. indica (L.) Gaertn.	goosegrass	.0	S	I	Poor mite host, immune to WSMV
Eragrostis					
E . pilosa (L.) Beauv.	India lovegrass	.0	R		Resists mites
Festuca L.	fescue	10.0	S	I	Immunity to WSMV
Glyceria					
G . striata (Lam.)	fowl mannagrass	.0			Resists mites, limited distribution
Hordeum					
H. jubatum L.	foxtail barley	.1			Limited distribution, poor mite host
H. pusillum Nutt.	little barley	11.2	S	I	Immunity to WSMV, early season maturity
Koeleria					
K. cristata (L.) Pers.	prairie junegrass	1.5	S		Poor mite host, limited distribution
Lolium					
L. perenne L.	perennial ryegrass	9.0	S		Poor mite host, limited distribution
Muhlenbergia					
M. mexicana (L.) Trin.	bearded wirestem muhly	4.4	S		Limited distribution, poor mite host

1. % of samples infested, each sample consisted of examining at least 50 seedlings, tillers, or culms unless mites were found sooner.
2. S = Susceptible, R = Resistant.
3. S = Susceptible, R = Resistant, C = Symptomless carrier of virus.

Table 2--Grasses examined in the field and/or laboratory and considered to be unimportant in epidemiology of wheat streak mosaic. (Continued)

Scientific and common name of grass		Field Examination % infested[1]	Laboratory reaction to Mites[2]	WSMV[3]	Major reasons for not being considered important in epidemiology of wheat streak mosaic
Panicum					
P. virgatum L.	switchgrass	.4	S	I	Immunity to WSMV, poor mite host
Pennisetum					
P. glaucum (L.) R. Br.	pearlmillet	18.0			Limited distribution
Phleum					
P. pratense L.	timothy	.0	S		Poor mite host, limited distribution
Poa					
P. annua L.	annual bluegrass	.0	S		Poor mite host, limited distribution
P. pratensis L.	Kentucky bluegrass	19.2	S	I	Immunity to WSMV, poor mite host
Polypogon					
P. monspeliensis (L.) Desf.	rabbitfoot polypogon	.0			Resists mites
Puccinellia					
P. airoides (Nutt.) Wats. & Coult.	nuttall alkaligrass	.0	R		Resists mites, limited distribution
Schedonnardus					
S. paniculatus (Nutt.) Trel.	tumblegrass	3.2	S		Poor mite host, early maturity
Sitanion					
S. hystrix (Nutt.) J. G. Smith	bottlebrush squirreltail	6.2	R	S	Limited distribution, poor mite host
Sorghastrum					
S. nutans (L.) Nash	indiangrass	.0	R	I	Resists mites, immunity to WSMV
Sorghum					
S. halepense (L.) Pers.	johnsongrass	.0	R	I	Resists mites, immunity to WSMV

1. % of samples infested, each sample consisted of examining at least 50 seedlings, tillers, or culms unless mites were found sooner.
2. S = Susceptible, R = Resistant.
3. S = Susceptible, R = Resistant, C = Symptomless carrier of virus.

Table 2--Grasses examined in the field and/or laboratory and considered to be unimportant in epidemiology of wheat streak mosaic. (Continued)

Scientific and common name of grass		Field Examination % infested[1]	Laboratory reaction to Mites[2]	Laboratory reaction to WSMV[3]	Major reasons for not being considered important in epidemiology of wheat streak mosaic
Spartina					
S. pectinata Link	prairie cordgrass	1.3			Poor mite host, limited distribution
Sporobolus					
S. neglectus Nash	puffsheath dropseed	3.7	S	S	Poor mite host, early plant maturity
Stipa					
S. comata Trin. & Rupr.	needleandthread	2.2	S		Poor mite host, early plant maturity
S. viridula Trin.	green needlegrass	.6	S		Poor mite host
Tripsacum					
T. dactyloides (L.) L.	eastern gamagrass	2.2	R	R	Poor mite host, limited distribution

1. % of samples infested, each sample consisted of examining at least 50 seedlings, tillers, or culms unless mites were found sooner.
2. S = Susceptible, R = Resistant.
3. S = Susceptible, R = Resistant, C = Symptomless carrier of virus.

Table 3--Grasses examined in the field and/or laboratory but not rated as to importance in epidemiology because of inadequate information.

Scientific name	Common name	Number of field collections: Examined	Number of field collections: Infested	Laboratory reactions to: Mites[2]	Laboratory reactions to: WSMV[3]
Agrostis					
A. alba L.	redtop	10	0		
Alopecurus					
A. carolinianus Walt.	Carolina foxtail	1	0		
A. pratensis L.	meadow foxtail	1	0		I
Chloris					
C. verticillata Nutt.	windmillgrass	22	0		
Dactylis					
D. glomerata L.	orchardgrass	30	0	R	I
Eragrostis					
E . reptans Michx.	hairy creeping lovegrass	8	0		
E. trichodes (Nutt.) Wood	sand lovegrass				S
Erianthus					
E. ravennae (L.) Beauv.	ravennagrass	4	0		
Eriochloa					
E. contracta Hitchc.	prairie cupgrass	1	0		
Euchlaena					
E . mexicana Schrad.	teosinte	1	0	R	I
Leersia Swartz	cutgrass	21	0		
Leptochloa					
L. fascicularis (Lam.) A. Gray	bearded sprangletop	1	0		
L. filiformis (Lam.) Beauv.	red sprangletop	1	0		
Melica L.	melic	6	0		
Miscanthus					
M. sinensis Anderss.	Chinese silvergrass	2	0		
Munroa					
M. squarrosa (Nutt.) Torr	falsebuffalograss	5	0	S	
Oryzopsis					
O. hymenoides (Roem & Schult) Ricker	Indian ricegrass			R	S

1. Each collection consisted of 50 to 100 seedlings or culms. Most collections were made at times when samples were present in nearby wheat fields.
2. S = Susceptible, R = Resistant.
3. S = Susceptible, R = Resistant, C = Symptomless carrier of virus.

Literature Cited

Anderson, K. L. and C. E. Owensby
1969. Common names of a selected list of plants. Technical Bulletin 117. Agricultural Experiment Station, Kansas State University.

Andrews, J. E. and J. T. Slykhuis.
1956. Reaction of winter wheat varieties and Triticum x Agropyron hybrids when inoculated with streak mosaic virus by the mite vector *Aceria tulipae* Keifer. Plant Disease Reporter 40: 513-516.

Ashworth, L. J. and M. C. Futrell.
1961. Sources, transmission, symptomatology, and distribution of wheat streak mosaic virus in Texas. Plant Disease Reporter 45: 220-224.

Atkinson, R. E.
1953. Studies on viruses of cereal grains. Ph. D. Dissertation, Univ. of Missouri, Publication 393783PP (Microfilmed, Univ. Microfilm, Ann Arbor, Michigan). (Bio. Abstracts 27, No. 6, 17998.)

Atkinson, T. G. and J. T. Slykhuis.
1963. Relation of spring drought, summer rains, and high fall temperatures to the wheat streak mosaic epiphytotic in southern Alberta. Canadian Plant Disease Survey 43: 154-159.

Bellingham, R. C.
1954. Unpublished U. S. Dept. Agric. Annual Report, 1954; on file at Beltsville, Maryland; Dept. of Botany and Plant Path., Kansas State University; and Fort Hays Experiment Station, Hays, Kansas.

Borgman, R. P.
1959. The epidemiology of wheat streak mosaic virus. Unpublished M. S. Thesis, Kansas State Univ., Manhattan, 129 pp.

Briones, Magdalena L.
1967. Effects of various temperatures on the survival of the wheat curl mite, *Aceria tulipae* Keifer. Unpublished M. S. Thesis, Kansas State Univ., Manhattan, 33 pp.

Connin, R. V.
1956a. Oversummering volunteer wheat in the epidemiology of wheat streak mosaic. Jour. Econ. Ent. 49: 405-406.

Connin, R. V.
1956b.The host range of the wheat curl mite, vector of wheat streak mosaic. Jour. Econ. Ent 49:1-4.

Connin, R. V. and R. Staples.
1957. RoIe of various insects and mites in the transmission of wheat streak mosaic virus. Jour. Econ. Ent. 50: 168-170.

Daniels, N. E.
1963. Eriophyid mite collections in the Texas panhandle. Annals Ent. Soc. of America 56: (6) 879.

del Rosario, M. S.
1957. *Aceria tulipae* (Keifer) (Eriophyidae) in relation to the transmission of wheat streak mosaic virus. Unpublished M. S. Thesis. Kansas State Univ., Manhattan, 87 pp.

del Rosario, M. S.
1959. Studies of *Aceria tulipae* (Keifer) (Eriophyidae) and other eriophyid mites in Kansas in relation to the transmission of wheat streak mosaic virus. Dissertation Abstracts 20: 863-864.

del Rosario, M. S. and W. H. Sill, Jr.
1958. A method of rearing large colonies of an eriophyid mite, *Aceria tulipae* (Keifer), in pure culture from a single egg or adult. Jour. Econ. Ent. 51: 303-306.

del Rosario, M. S. and W. H. Sill, Jr.
1965. Physiological strains of *Aceria tulipae* and their relationships to the transmission of wheat mosaic virus. Phytopathology 55 : 1168 - 1175.

Fellows, H. and J. W. Schmidt.
1953. Reaction of Agrotricum hybrids to the virus of yellow streak mosaic of wheat. Plant Disease Reporter 37: 349-351.

Fellows, H. and W. H. Sill, Jr.
1955. Predicting wheat streak mosaic epiphytotics in winter wheat. Plant Disease Reporter 39: 291-295.

Finley, A. M.
1957. Wheat streak mosaic, a disease of

sweet corn in Idaho. Plant Disease Reporter 41: 589-591.

Ford, R. E. and R. C. Lambe.
1967. Wheat streak mosaic virus incidence in Iowa. Plant Disease Reporter 51:389.

Gates, Frank C.
1936. Grasses in Kansas. Report of the Kansas Board of Agriculture. Vol. LV, No. 220-A. Topeka, Kansas. 349 p., illus.

Gibson, W. W.
1957a. Observations of wheat curl mite *Aceria tulipae* (K.), (Acarina, Eriophyidae) on wheat and sorghum sprouted under ripening wheat. Jour. Kans. Ent. Soc. 30: 25-28.

Gibson, W. W.
1957b. Biological and ecological studies of the wheat curl mite, *Aceria tulipae* (K.), on winter wheat in Kansas. A Ph.D. Dissertation. Kansas State University, Manhattan, 148 p.

Hall, C. C., Jr.
1958. A new eriophyid mite from Kansas. Jour. Kans. Ent. Soc. 31: 233-235.

Haskett, W. C., W. H. Sill, Jr., C. O. Johnston, E. D. Hansing, and H. Fellows.
1956. Kansas Phytopathological notes; 1954. Trans. Kans. Acad. Sci. 59: 51-56.

Harvey, T. L.
1951. Transmission experiments involving possible insect vectors of the virus *Marmor virgatum* var. *typicum* McKinney, which causes wheat streak mosaic. Unpublished M. S. Thesis. Kansas State University, Manhattan.

Kantack, E. J. and Herbert Knutson.
1954. Locations of maximum numbers of wheat curl mite, *Aceria tulipae* (K.), (Eriphyidae) on the winter wheat plant during spring growth. Field Laboratory 22: 65-67.

Kantack, E. J. and Herbert Knutson.
1958.Chemical control studies of the wheat curl mite. Jour. Econ. Ent. 51: 68-72.

Keifer, H. H.
1938. Eriophyid studies, Calif. Dept. Agric. Bull. 27: 181-206.

Keifer, H. H.
1952. The eriophyid mites of California (Acarina: Eriphyidae). Bull. Calif. Insect Survey, Vol. 2, No. 1.

Lal, Sadar B.
1957. Strains of wheat streak mosaic virus and their combinations with barley stripe and brome mosaic viruses. Unpublished Ph. D. dissertation. Kansas State University, Manhattan. 126 pp.

McKinney, H. H.
1937. Mosaic diseases of wheat and related cereals. U. S. Dept. Agric. Circular 442. 22 pp., illus.

McKinney, H. H.
1944. Descriptions and revisions of several species of viruses in the genera *Marmor, Fractilinea*, and *Galla*. Jour. Wash. Acad. Sci. 34: 322-329.

McKinney, H. H.
1949. Tests of varieties of wheat, barley, oats, and corn for reaction to wheat streak mosaic virus. Plant Disease Reporter 33: 359-369.

McKinney, H. H. and H. Fellows.
1951., A method for inoculating varietal test nurseries with the wheat streak mosaic virus. Plant Disease Reporter 35 : 264-266.

McKinney, H. H. and Hurley Fellows.
1951. Wild and forage grasses found to be susceptible to the wheat streak mosaic virus. Plant Disease Reporter 35: 441-442.

McKinney, H. H. and W. J. Sando.
1951. Susceptibility and resistance to the wheat streak mosaic virus in the genera Triticum, Agropyron, Secale, and certain hybrids. Plant Disease Reporter 35 : 476-479.

McKinney, H. H., Myron K. Brakke, Ellen M. Ball, and Robert Staples.
1966. Wheat streak mosaic virus in the Ohio Valley. Plant Disease Reporter 50: 951-953.

Pady, S. M.
1955. The occurence of the vector of wheat streak mosaic, *Aceria tulipae*, on slides exposed in the air. Plant Disease Reporter 39: 296-297.

Pady, S. M., C. O. Johnston, W. C. Haskett, W. H. Sill, Jr., E. D. Hansing, H. Fellows, C. T. Rogerson, and J. C. Frazier.
1955. Diseases of wheat in Kansas. Kansas Agricultural Expt. Station, Bulletin 368. 24 pp., illus.

Painter. R. H. and John Schesser.
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.

Schmidt, J. W., W. H. Sill, Jr. and H. Fellows
1956. Range of reactions to wheat streak mosaic virus in hybrids derived from *Triticum vulgare x Agropyron elongatum*. Agron. Jour. 48: 371-373.

Sill, W. H., Jr.
1953a. Some characteristics of the wheat streak mosaic virus and disease. Trans. Kansas Acad. Sci. 56: 418-424.

Sill, W. H., Jr.
1953b.Wind and blowing soil as factors in the spread of wheat streak mosaic virus. Phytopath. (Abstr.) 43 : 484.

Sill, W. H., Jr.
1959. Wheat Streak mosaic. Kans. Agric. Expt. Station Reprint No. 1 (from Kans. Agric. Situation, Aug. 1959), pp. 8-10.

Sill, W. H.. Jr. and R. V. Connin.
1953. Summary of the known host range of the wheat streak mosaic virus. Trans. Kansas Acad. Sci. 56: 411-417.

Sill, W. H., Jr. and H. Fellows.
1953. Symptom expression of the wheat streak mosaic virus disease as affected by temperature. Plant Disease Reporter 37: 30-33.

Sill, W. H., Jr. and P. Agusiobo
1955. Host range studies of the wheat streak mosaic virus. Plant Disease Reporter 39: 633-642.

Sill, W. H., Jr., and Maria S. del Rosario.
1959. Transmission of wheat streak mosaic virus to corn by the eriophyid mite, *Aceria tulipae*. Phytopath. 49: 396.

Sill, W. H., Jr., Roscoe C. Bellingham, and Hurley Fellows.
1964. Reactions of wheat, wheat crosses, barley, rye, and oats to wheat streak mosaic virus. Kansas State University Agric. Expt. Station, Tech. Bulletin 132. 15 pp. illus.

Slykhuis, J. T.
1951. *Setaria viridis*, a host of wheat mosaic. Plant Disease Reporter 35 : 221.

Slykhuis, J. T.
1952. Virus diseases of cereal crops in South Dakota. S. D. Agr. Expt. Sta., Tech. Bull. 11: 29 pp., illus.

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.

Slykhuis, J. T., J. E. Andrews, and U. J. Pittman.
1957. Relation of date of seeding winter wheat in southern Alberta to losses from wheat streak mosaic, root rot, and rust. Canadian Jour. of Plant Sci. 37: 113-127.

Somsen, H. W.
1966. Development of a migratory form of wheat curl mite. Jour. Econ. Ent. 59: 1283.

Staples, R. and W. B. Allington.
1956. Streak mosaic of wheat in Nebraska and its control. Univ. of Neb. College of Agr. Expt. Station. Research Bull. 178, 40 pp.

Staples, R. and W. B. Allington.
1959.The efficiency of sticky traps in sampling epidemic populations of the eriophyid mite *Aceria tulipae* (K.), vector of wheat streak mosaic virus. Ann. Ent. Soc. Amer. 52: 159-164. (Bio. Abstrs. 33: 2883 (35260), 1959).

Tuttle, D. M. and G. D. Butler.
1961. A new eriophyid mite infesting Bermudagrass. Jour. Econ. Ent. 54: 836-838.