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VIRUS DISEASES OF PLANTS IN ARIZONA. II

Field and Experimental Observations on Curly-Top Affecting Vegetable Crops

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COVER

Symptoms caused by curly-top virus in tomato. Note the yellow color of the diseased plants. The green plants are either uninfected or harbor only mild invasion of the virus. Experimental Planting, University of Arizona Experiment Station, Mesa.

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SUMMARY

Virus strains responsible for curly-top infections in Arizona are notable for: (a) their wide distribution, (b) ability to attack numerous vegetable, field and forage crops, as well as a great many ornamental plants and weeds, and (c) their destructiveness which may range from disguised effects invisible in the field to total destruction of the affected plants.

External symptoms of curly-top virus infection may appear in leaves, stems, flowers, fruits or roots of infected plants. Generally, mottling is absent, but infected plant parts may become distorted through curling, twisting, rolling, stunting, etc. Leaves become thickened and leathery. Both yield and quality of the product of an infected plant may be impaired by curly-top virus. Fruits frequently ripen prematurely, have an insipid taste and reduced sugar content. This is especially true in melons and other cucurbits and in tomatoes.

Some of the most pronounced symptoms resulting from curly-top virus attacks are internal and non-observable with the unaided eye. Such internal symptoms consist of death (necrosis) of the food-conducting vessels (phloem), as well as of extreme variations from the normal in numbers and sizes of cells composing the plant tissues involved.

Curly-top virus is transmitted only by the sugar-beet leafhopper, *Circulifer tenellus* (Baker). So far as is known, no strain of curly-top virus is easily transmitted mechanically. True seed transmission does not occur, although in potatoes the persistence of the virus in tubers and seed-pieces prepared from such tubers has been reported.

Although curly-top virus is difficult to control, some suggestions designed to lessen the severity of attacks are included. Losses can be reduced in many instances by: (a) use of resistant varieties of plants, (b) pursuit of sanitary measures including the eradication and destruction of susceptible weeds, as well as susceptible volunteer crop plants from a previous planting, (c) regulating the time of planting in order to avoid the main flights of the sugar-beet leafhopper (*Circulifer tenellus*) which transmits curly-top virus in Arizona, (d) use of barriers either in the form of barrier or trap crops and mechanical barriers of fine-mesh materials, and (e) insecticides. Other control measures are discussed in this bulletin.

VIRUS DISEASES OF PLANTS IN ARIZONA. II. FIELD AND EXPERIMENTAL OBSERVATIONS ON CURLY-TOP AFFECTING VEGETABLE CROPS

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INTRODUCTION

A previous bulletin (18)[2] was devoted to general information concerning plant viruses and virus diseases. It also included descriptions and illustrations of some of the common field responses of plants to infections by widespread and numerous strains of mosaic viruses. Some relationships among mosaic viruses to vegetable crops as well as to ornamental plants and weeds were pointed out. Methods by which mosaic viruses are transmitted were discussed. Suggestions designed to reduce losses from mosaic viruses were also offered. In order to secure some of the general information about plant viruses and plant virus diseases, the reader should consult the previous publication (18).

This bulletin is concerned with field and experimental observations on the reactions of plants, particularly of vegetable crops, to infections by strains of North American Curly-top virus. As in the previous bulletin (18), emphasis has been placed on symptoms in Arizona plants.

Records and results of experiments up to July 1, 1955, served as sources for the material in this bulletin.

ECONOMIC IMPORTANCE

In spite of outstanding progress in developing varieties of plants resistant to curly-top virus attacks, particularly in the fields of garden- and sugar-beet culture, curly-top virus strains cause considerable damage in vegetable and other crops. In sections of the western United States, the almost total loss of tomato plantings in some seasons due to curly-top virus attack is a matter of record.

The realization that individual infected plants may show no external symptoms of curly-top virus infection and yet yield an inferior product indicates that much of the damage caused by this virus and its strains is frequently disguised and overlooked in the field. Tomato, melon, and squash plants which have become infected and have overcome visible symptoms of attack may still yield externally acceptable fruits although internal abnormalities may be present. Such fruits usually possess a peculiar flavor and have a low sugar content.

RANGE

Curly-top virus is rather widespread in melons in the field in both Arizona and California.[3] The presence of curly-top virus in cantaloupes and honeydew melons

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[1]Department of Plant Pathology, Agricultural Experiment Station, University of Arizona, Tucson.

[2]Numbers in parentheses refer to "Literature Cited" at end of bulletin.

[3]Dr. N. J. Giddings, formerly of the Division of Sugar Plant Investigations, United States Department of Agriculture, Riverside, California, recovered curly-top virus from both vines and fruits of cantaloupe and honeydew melons, from materials sent to him by the writer from the Salt River Valley of Arizona (11).

may help to account for some of the off-flavor and poor quality noted in some years in these fruits. Of interest are the recent isolations by Giddings (13, 14), of a highly infective strain of curly-top virus from field-infected potatoes. Menzies and Giddings (19), showed that curly-top virus in potatoes produces the condition which has been known as Green Dwarf since 1946 in Oregon.

Until recently, curly-top virus was believed to be confined entirely to the western United States. It was only occasionally that the sugar-beet leafhopper, *Circulifer tenellus* (Baker) was found east of the Rockies (15). Prior to 1953, sugar-beet leafhoppers had been reported only twice from east of the Mississippi river (6). In 1953, rather substantial migrations of beet leafhoppers took place from southern New Mexico and western Texas into the sugar-beet producing areas of southwestern Kansas (6). These migrations were accompanied by severe outbreaks of curly-top. Previous to 1953, no proven case of curly-top attack had been demonstrated east of Jacksonville, Texas (15). The range of the virus and that of the vector have now been extended to include areas other than in the west. The virus has been shown to cause disease in beets in Illinois, Iowa, and Minnesota (15, 20).

At the present time, curly-top is the most widespread and destructive virus disease affecting vegetables and other crops in Arizona. Strains of North American curly-top virus are widely distributed throughout the State. Records of the virus have been made from 13 of the 14 counties. No reports of curly-top have ever been made from Mohave County.

Areas other than Arizona located in the West have been sites for the occurrence of curly-top virus in destructive amounts in such crops as tomatoes. The almost yearly destruction of tomato plants by curly-top virus in both large-scale and small-scale plantings is well known to growers. Periodic losses occur in tomatoes in the San Joaquin Valley in California.

Although North American Curly-top virus probably existed in Arizona prior to 1926, the first official records were made in that year. The reports indicate that in some instances, the prevalence of the virus in tomatoes was rather high. At that time, the disease was designated "Western Yellows" or "Western Yellows Blight." Both of these names have since been discarded to avoid confusion with diseases of the same crop caused by agents other than viruses.

Strains other than those belonging to typical North American Curly-top virus have been described (3, 4, 5, 7).

CROPS AFFECTED

Crops such as beans, beets, melons, peppers, pumpkins, radishes, spinach, squashes, and tomatoes among others (see Appendix for a more extensive listing), are highly susceptible to strains of North American Curly-top virus. In addition to vegetables, many field and forage crops, as well as ornamental plants and weeds, are susceptible. Susceptible field crops include alfalfa, flax, guar, and others. Among ornamental plants susceptible to curly-top virus are: geranium, nasturtium, petunia, stocks, and zinnia.

Many weeds are also susceptible to the virus. Among these are species of *Atriplex, Barbarea, Brassica, Chenopodium, Erodium* (filaree), *Plantago, Sonchus* (sow thistle), and others. Russian Thistle *(Salsola pestifer)* so common along roadsides throughout Arizona is a host for the leafhoppers which transmit strains of curly-top virus. Much of our knowledge concerning the number and variety of plants susceptible to strains of curly-top virus has been gained through the investigations of Freitag, Severin, and Henderson (8, 21, 22).

SYMPTOMS — GENERAL

Many plants susceptible to curly-top virus react similarly. That is, in many instances symptoms of the disease are identical or quite similar in different hosts infected by any given strain.

The symptoms described and illustrated in this bulletin are generally characteristic for the disease. There are some variations among different plants infected with the same virus strains. These are largely the result of response of the plant to different environmental conditions.

Tomato, pepper, and certain other plants infected with curly-top virus have been known to recover from symptoms to a certain degree. This recovery is sometimes enduring; at other times affected plants recover, then suffer relapses, with intense disease symptoms reappearing. Recovery from disease symptom expression may lead to the false assumption that infected plants are virus-free and have "escaped" infection.

There are, also, cases in which certain varieties of plants act as symptomless carriers of curly-top virus throughout the entire growth period of the infected specimen. These situations are similar to those later mentioned under "Symptoms in Stems," in which no external symptoms of disease are evident even when internal abnormalities exist. In any of the foregoing cases, the virus still remains in an active state within the invaded plants.

Curly-top virus may infect a plant at any stage of development, from the seedling through maturity.

Hills and Taylor (17) assert that the earlier the stage in which cantaloupe plants are infected, the more severe is the damage from curly-top virus. For example, they found that plants infected in the cotyledon and 2-leaf stages are stunted or killed. Plants in the 4-leaf stage survived infection, but were stunted and usually had reduced yield. Plants in the 6-leaf stage with runners averaging 8 inches were damaged to a lesser degree. It is generally true in most plant virus infections that the younger the plant is at the time of infection, the more spectacular will be the symptoms and the resulting damage.

The conclusion drawn by Hills and Taylor (17) is that there is a "build-up in resistance" in older cantaloupe plants. In an earlier investigation, Hills and Taylor (16) concluded that PMR 45 cantaloupe plants develop some resistance to curly-top virus between the cotyledon and 2-leaf stages of development. It is entirely possible in these cases that older plants develop greater "tolerance" to the virus and do not react to infection as severely as do younger ones. Tolerance in older plants does not necessarily imply an increase in resistance.

The virus is still present in older plants in variable concentrations and frequently can be recovered readily from medium-sized and mature fruits (See "Symptoms in Fruits," p. 12).

Two or more strains of curly-top virus may exist together simultaneously in a single plant (12). In addition, some plants infected with curly-top virus may apparently also contain other unrelated viruses at the same time. A mosaic virus that induced symptoms of the well-recognized "oak-leaf" pattern when viewed in transmitted light was found to be present along with curly-top virus in plants of Texsel Guar at the University of Arizona Experiment Station, Mesa.[4]

The prevalence of curly-top virus varies from season to season. In some years there are severe attacks; in others, only minor ones.

Whenever mild to severe symptoms occur in plants infected by strains of curly-top virus, they may be readily recognized. Much of the following information is based on reactions of highly susceptible plants, such as tomatoes, garden- and sugar-beets, squashes, and peppers. Melons, which are also susceptible, frequently do not exhibit easily detectable symptoms of infection.

Noteworthy in most plants infected by curly-top virus is the almost complete absence of mottling in the symptom pattern. This is in contrast to infections of Arizona vegetables by other viruses, especially mosaic viruses (18). Mottling has been observed in Arizona, however, in turnips infected with curly-top virus. If any discoloration (chlorosis) does occur, it is usually general over the entire plant rather than localized (See Cover; Plate VII, A). Curly-top infected plants may be of a darker color than is normal for that particular plant species.

LEAF SYMPTOMS

Leaf surfaces — Puckering, (Plates I, B; VIII, A, B) due to differences in growth rates in veins and interveinal tissues, is an early and striking symptom of curly-top virus infection in many plants. In some instances, this reaction becomes so pronounced that a "snakeskin" effect results, the interveinal areas actually becoming raised (Plate I, B). In other plants, such as melons, leaf surfaces show little or no reaction to infections (Plate VI, A, B).

Leaf outline, margin, and size — In most plants, the edges (margins) of infected leaves roll inward and upward toward the mid-veins (Plates II, III, B; IV, V, VI, VII, A (at right), B; IX, XII, A). This rolling is especially striking in infected tomato and beet plants. In tomato, in addition to the margins of the individual leaflets rolling inward, the entire leaf (sum total of all of the leaflets) bends downward (Plates IV, V). In garden and sugar beets, peppers, squashes, and others, the entire leaf is involved sometimes in the inward rolling of the margins toward the mid-vein (Plates I, B; II, III, B; VIII, A, B; XI). As a result of the margin or of the en-

[4]Dr. N. J. Giddings, formerly of the United States Department of Agriculture, Division of Sugar Plant Investigations, Riverside, California, proved the existence of curly-top virus in naturally infected Texsel Guar plants sent to him by the writer from plantings at the Mesa Experiment Station in 1947. Many of the same plants were also infected by an unidentified mosaic virus.

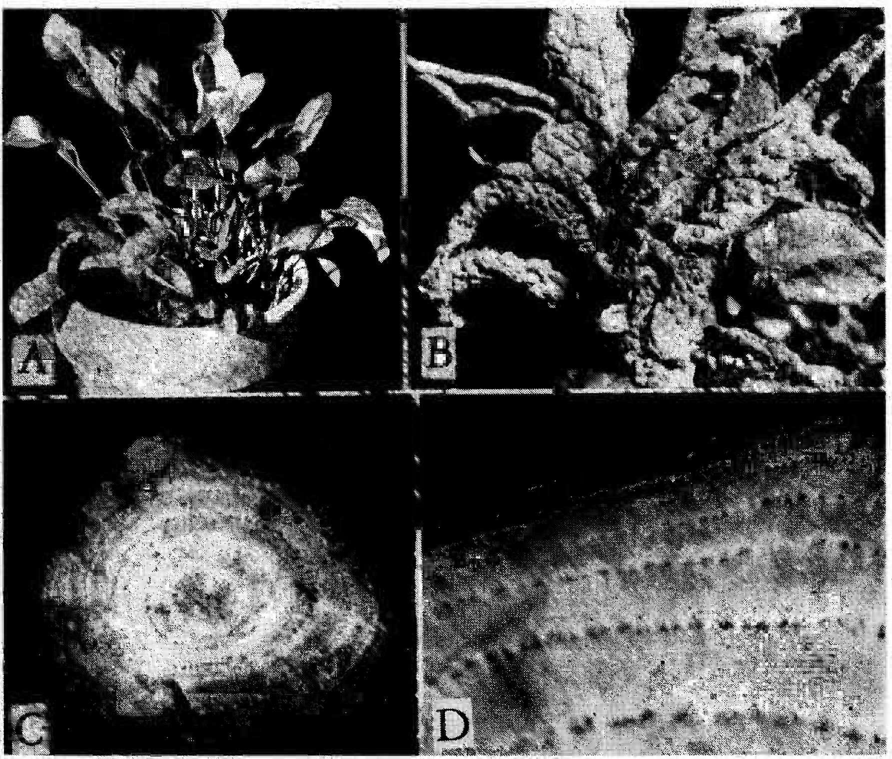

Plate I. — Healthy and curly-top virus infected garden beet. A. Non-infected, healthy plant. B. "Snakeskin-like" effect in leaves of curly-top infected plant. C. Cross-section of a root showing dot-like discolored areas consisting of dead (necrotic) food-conducting tissue (phloem). D. Enlarged portion of a cross-section showing individual necrotic phloem areas.

tire leaf rolling and undergoing other distortions, the leaf outline is greatly altered (Plates I, B; II, III, B; IV, V, VI, VII, B; VIII, A, B; IX, XI, XII).

Leaf veins — The earliest symptom of curly-top virus invasion in most plants is vein clearing. During this process affected veins become transparent. Vein clearing precedes or occurs simultaneously with other symptoms in leaves. Sometimes vein clearing appears in only one portion of a leaf. Vein clearing may best be detected in such susceptible plants as sugar beet by placing an infected leaf between some light source and the observer. Early-

Plate II. — Symptoms caused by curly-top virus in sugar beet. The inward rolled leaf margins are evident.

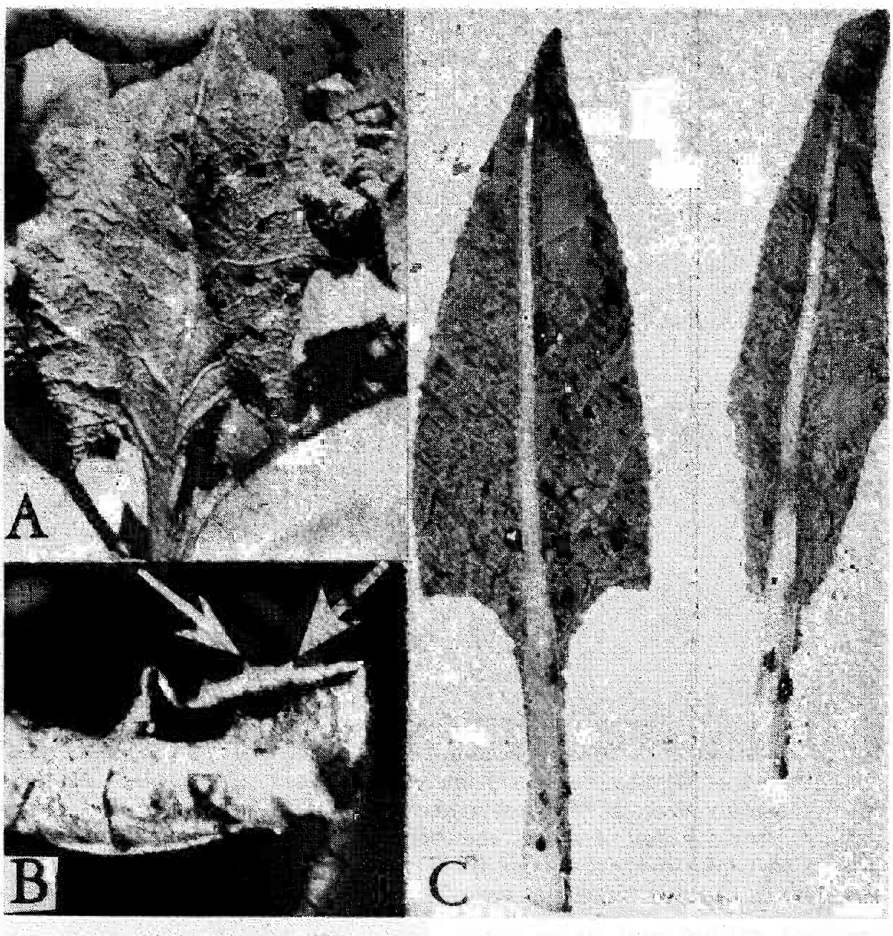

Plate III. — Symptoms caused by curly-top virus in leaves of beet. A. Roughened veins particularly pronounced on the lower surface of infected leaves. The roughness is due to outgrowths or papillae from the veins. B. Enlarged portion of lower leaf surface showing two outgrowths or papillae (at arrows). C. Droplets of dark-brown to black sticky exudate represented by dot-like areas in photograph, on leaves and leaf stems (petioles) of infected plants. (Photo C, courtesy of the United States Department of Agriculture, Division of Sugar Plant Investigations).

stage infections by strains of curly-top virus can be detected in this manner.

During late stages in leaf infections in certain plants, veins become purplish. This is particularly true in tomato (e.g., Plate IV, the dark-colored veins in the leaflets in the lower foreground) and in pepper. However, purpling of the veins may result from causes other than curly-top virus infections. This, therefore, is not a reliable diagnostic character.

Other leaf symptoms — A striking reaction to infection by strains of curly-top virus is the production of papillae or small, wart-like

Plate IV. — Symptoms of curly-top virus attack in tomato. The margins of the leaflets are rolled inward toward the mid-veins. Dark-colored veins (in nature, purple-colored) in leaflets in the foreground are evident.

outgrowths on veins of leaves (Plate III, A, B, at arrows). These outgrowths occur on the undersides of leaves and may become quite prominent at times. This is especially true in infected garden and sugar beets. These outgrowths cause the veins of leaves to appear enlarged and roughened (Plate III, A).

In garden and sugar beets, severe infections are often accompanied by the production of a dark brown, slightly sticky liquid on the surfaces of the leaves and leaf stems (petioles) (Plate III, C). This liquid becomes black and hardened on drying.

In mid- to late stages of infection, tomato plants become yellow-green, then yellow in color (See cover). Much of the yellowish coloration appears to be due to two factors: (a) the virus apparently aids in the early destruction of chlorophyll, and (b) there is an excessive exudation of yellow honeydew-like material through natural openings in infected leaves and stems under Arizona climatic conditions. There may be so much of this material that it simulates intense honeydew production from severe aphid attack.

Curly-top virus infected leaves become thickened and leathery.

Plate V. — Symptoms of curly-top virus infection in tomato. While the margins of the leaflets roll inward, the whole leaf (sum total of leaflets) bends downward. This symptom is evident in this illustration.

This condition is supposedly the result of an accumulation of starch.

In late stages, curly-top virus infection causes plants to collapse and die.

Giddings (12) has described comparative symptoms caused by strains of curly-top virus in a susceptible variety of sugar beet (S. L. 842) and in a resistant type (S. L. 68). He used forty-two possible paired combinations. He found no cross protection from symptom development in any of the forty-two paired combinations.

STEM SYMPTOMS

The stem internodes (areas between the points where leaves arise) of curly-top virus infected plants are shorter than is normal for that species. This results in a bunching of the leaves, especially at or near the tips. In vine-like plants such as melons, the terminally-bunched leaves are striking (Plate VI, A).

In ornamental plants, many of which are susceptible to attack, infected stems often become twisted and distorted. This is a very common symptom in *Zinnia*.

Aside from a few externally visible reactions associated with curly-top virus infections, by far the most pronounced stem changes are internal. Most of these internal changes are invisible in the field, but may be seen with the aid of a compound microscope.

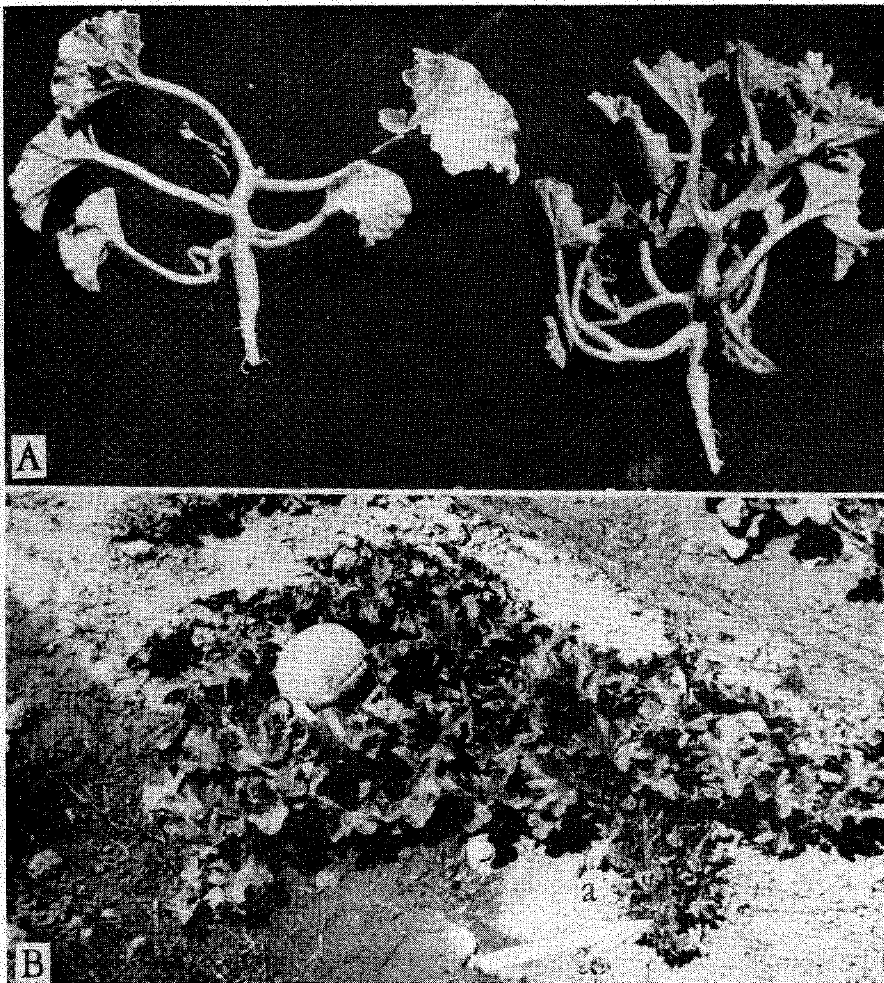

Plate VI. — Difficult-to-detect symptoms of curly-top virus attack in cantaloupe. A. At left, a healthy seedling. At right is a diseased seedling showing the characteristic bunching of leaves, particularly near the stem tip. B. A single plant with one runner (a, and arrow) showing leaves with inwardly rolled margins.

Some internal stem symptoms are observable in the field with the unaided eye or with the aid of a magnifying glass of low power. Since internal stem symptoms caused by curly-top virus approximate some of the stem symptoms caused by other disease-inducing agents such as fungi, error in diagnosis may result. Recourse to the microscope is the only sure method of detecting the internal stem symptoms, which occur in most susceptible plants. Cantaloupe, honeydew melon, and watermelon plants, on the other hand, usually show no outstanding internal stem symptoms.

If main or leaf stems (petioles) of most plants infected with curly-

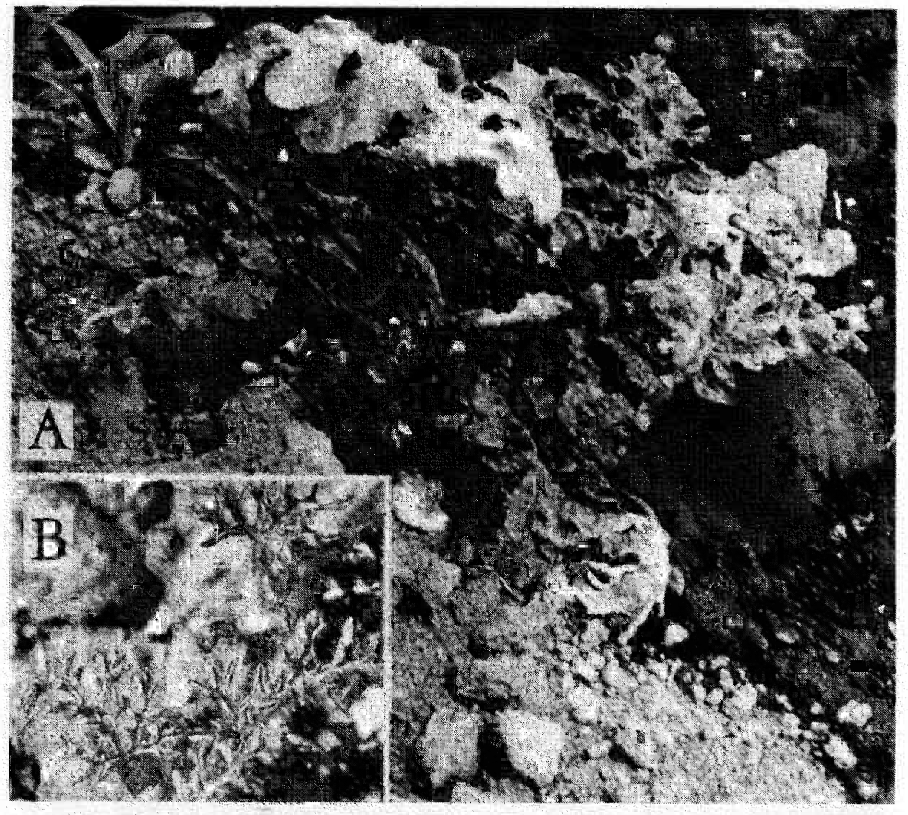

Plate VII. — Symptoms caused by curly-top virus in watermelon. A. Light-colored or chlorotic plant (in nature, yellowish) showing immature fruit. B. Extreme curling and chlorosis of leaves due to virus infection.

top virus are cut crosswise, light to dark yellow-brown, brown, to dark-brown or black, dot-like areas are observable. These discolored, dot-like areas are arranged generally in the form of one or more circles. (Fig. 1; Plate I, C). The "dots" are actually masses of plant cells which have become functionless due to the presence of the virus. These functionless cells are located in the food-conducting tissues (phloem). The deterioration and death of these cells is known as phloem necrosis (Fig. 2; Plate I, C, D). Non-infected or healthy plants show no disorganization of the phloem areas (Fig. 3). Death or necrosis of the phloem, cutting off all exchanges of nutrients and elaborated foods between various organs of infected plants, results in the final collapse of diseased specimens.

The discolored, necrotic phloem regions of curly-top virus infected plants should not be confused with discolored areas which may occur in the xylem (water and nutrient-conducting tissue) of diseased plants. Xylem discoloration is noticeable in such plants as tomato infected by the tomato wilt fungus, *Fusarium* sp. In Arizona, this fungus and curly-top virus

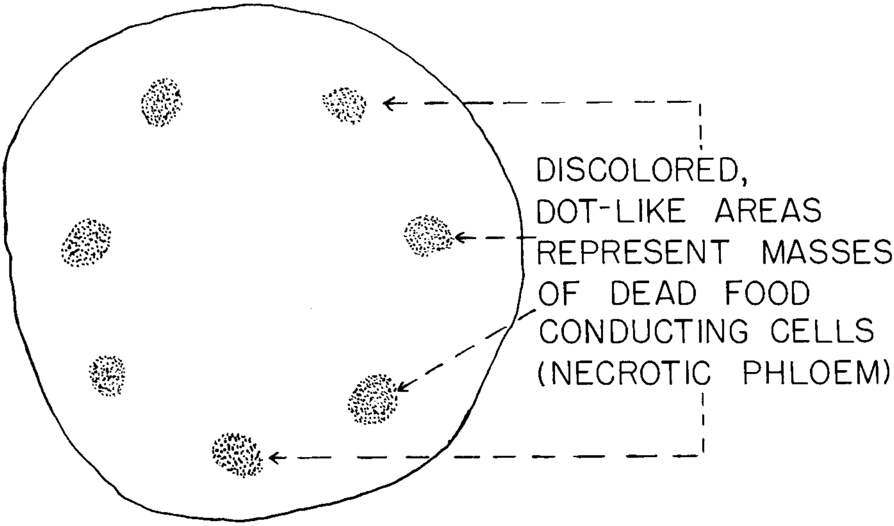

Figure 1. — Diagrammatic representation of a cross-section of a curly-top virus infected tomato stem, showing the approximate locations of the dead (necrotic) food-conducting vessels (phloem).

are frequently found together in diseased tomato plants. In these cases the determination of the primary cause of decline is not known. Microscopic examination will disclose whether *Fusarium* is present.

The apparent ability of curly-top virus to persist in Irish potato tubers is significant. Structurally, Irish potato tubers are modified stems. Externally, curly-top virus infected potato tubers show no symptoms. The presence of "hidden virus" in such modified stems is of importance to the grower in efforts to maintain disease-free stock. It is especially significant to the potato seed producer.

Phloem necrosis may appear in many curly-top virus infected plants even when no external symptoms or evidence of plant illness are present. Studies on tomatoes in experimental plantings at the Arizona Agricultural Experiment Station, Tucson, show that even though no symptoms of curly-top virus attack are externally visible, high percentages of plants may be invaded. In this sense, tomato plants may act as "symptomless carriers" throughout an entire season. Fruit production in such plants is usually only slightly below normal for the variety. However, such plants continue to serve as sources or reservoirs for hidden virus from which subsequent spreads may occur to other susceptible plants.

In experiments conducted by the author at the Arizona Agricultural Experiment Station, Tucson, sections from stems of externally symptomless tomato plants, when examined with a compound microscope, invariably showed intense phloem necrosis, indicative of curly-top virus invasion. Sections selected at random indicated that the virus was well distributed throughout the plants and was not confined to specific areas.

In these experiments, it was also found that the position of any one variety of tomato in the row, as well as the position of that

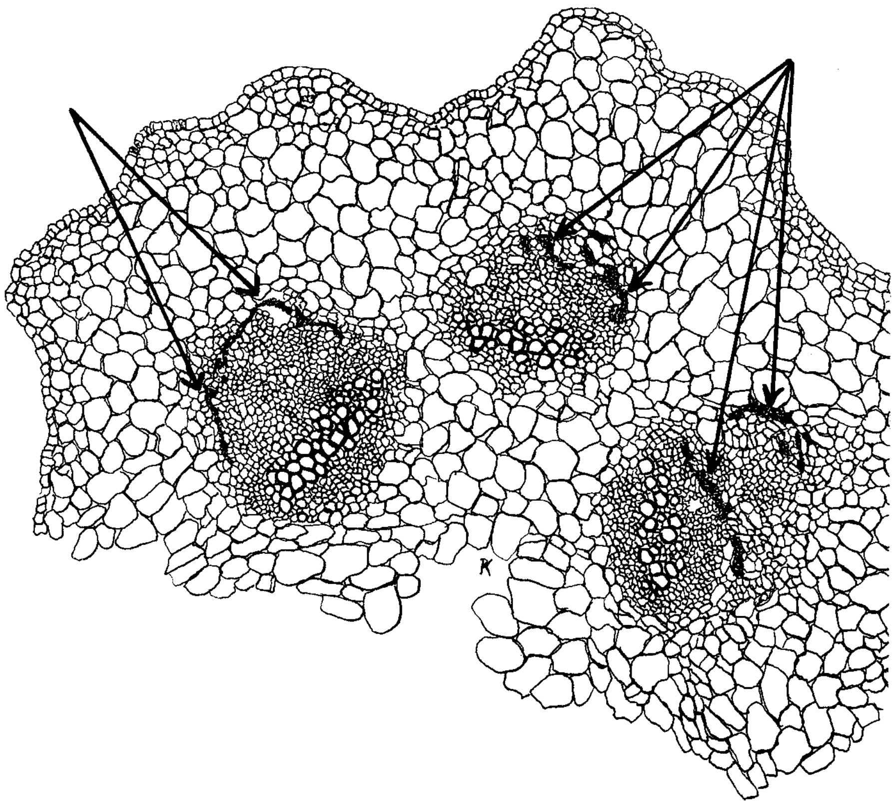

Figure 2. — Portion of a stem of tomato showing details of the necrotic phloem areas (at arrows). The large, open-like cells beneath the phloem areas are groups of xylem vessels which do not show discoloration or necrosis (death) if curly-top virus alone is present.

variety in the plots, did not influence the presence or absence of phloem necrosis. The data also show that there were no differences among the seven varieties with respect to susceptibility to curly-top virus attack (Table 1).

Other viruses, for example, the potato leafroll virus in potato and the phloem necrosis viruses of elm and tea, may cause death (necrosis) of the phloem. Necrotic phloem has also been observed in Arizona in potatoes infected with the virus complex causing purple-top wilt. This disease, at least in Arizona, appears to be due to a complex involving both leafroll and aster-yellows viruses.

Stems in many plants infected with curly-top virus become hollow, especially during late stages of invasion. However, hollow stems do not necessarily indicate virus attack. In some plants such as watermelon, cantaloupe and honeydew melon, the center of the stem is normally hollow.

FLOWER SYMPTOMS

Flowers of plants infected by strains of curly-top virus are generally smaller than normal, and are usually much distorted. These

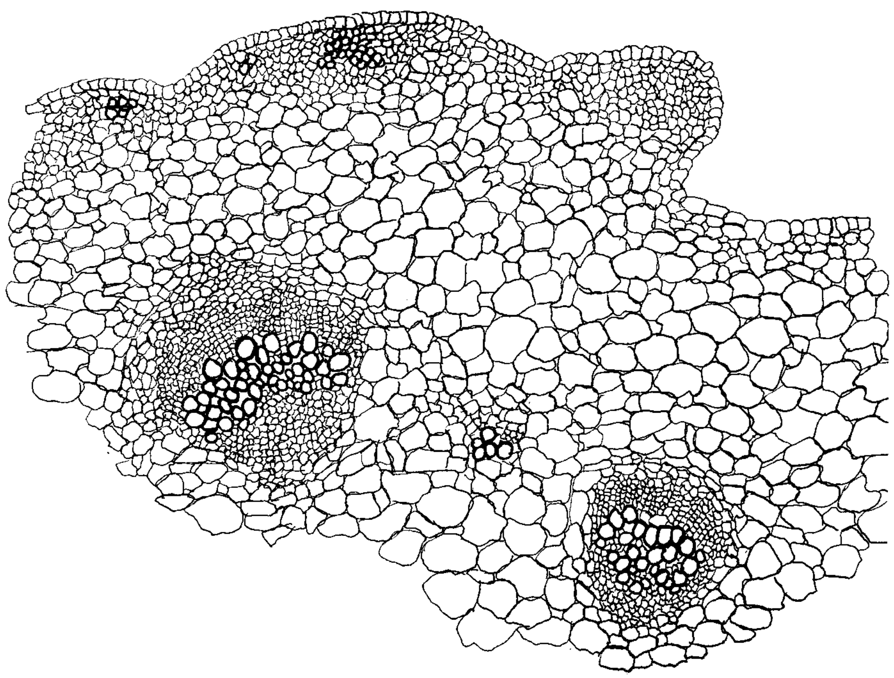

Figure 3. — Portion of a healthy, non-infected stem cross-section of tomato. Note the absence of discolored, necrotic food-conducting tissues (phloem). Compare with Fig. 2.

symptoms are more evident in flowers of infected ornamental plants. Since some crops are harvested before they reach the flowering stage, symptoms do not appear in these structures. In other cases, flowers of some plants such as broccoli and cauliflower, both of which are susceptible to curly-top in Arizona, show no reaction to attack.

FRUIT SYMPTOMS

Fruits of plants infected with curly-top virus exhibit a variety of symptoms. Infected fruits tend to ripen prematurely. This is particularly true in the case of tomato, in which infected fruit assumes the typical color expected at maturity without ripening normally. The flavor of a curly-top infected tomato fruit is often abnormal and frequently approaches bitterness. In melons, particularly cantaloupes, the poor flavor and quality of fruits sometimes noticeable may be due in part to curly-top virus infections. It is known that infected fruits often have a low sugar content.

In addition to premature ripening with the resulting off-flavor and composition, infected fruits may exhibit changes in color from the normal. The shape of infected fruits may be considerably altered (Plates IX, arrow; XI). At times, fruits may assume an abnormal position on an infected plant (Plate X, B). The skin of infected fruits is usually tough and wrinkled.

Plate VIII. — Symptoms of curly-top virus infection in beans. A. At left is a curly-top infected Pinto bean plant. Note the stunting and distorted leaves. At right, a healthy non-infected plant. B. Plants of string bean showing roughened leaves due to curly-top virus attack. C. Greatly enlarged view of a single adult of sugar-beet leafhopper (Circulifer tenellus) (Baker), the only known vector of curly-top virus in Arizona. These insects are quite small, measuring about one-eighth to three-sixteenths inch in length and one-sixteenth to one-eighth inch broad.

In spite of the absence of externally spectacular symptoms in infected fruits, these structures are apparently a good source of the virus. Giddings (11) stated that he recovered curly-top virus readily from small to half-grown cantaloupe and honeydew fruits. The materials used by Giddings were from the Salt River Valley of Arizona.

ROOT SYMPTOMS

Some roots infected with curly-top virus produce an excessive

TABLE 1. — Results of microscopic examinations of tomato plants showing no external symptoms of curly-top virus attack.

Variety	Position of variety in row	Plants examined	Plants showing phloem necrosis	Sections examined	Sections showing phloem necrosis
		number	*number*	*number*	*per cent*
Ponderosa (Beefsteak)	I	12	12	51	76.5
Improved Pearson	II	23	23	91	99
Foremost Hybrid	III	11	10	45	53
Marglobe	IV	16	16	64	77
Stone	V	16	16	64	92
Earliana	VI	17	17	66	92
Victor	VII	10	10	36	92
Foremost Hybrid	VIII	20	20	81	88
Stone	IX	10	10	40	88
Improved Pearson	X	27	27	209	86
Victor	XI	20	20	80	93
Marglobe	XII	37	37	147	78
Earliana	XIII	31	31	121	82
Ponderosa (Beefsteak)	XIV	30	30	123	89
Improved Pearson	XV	24	23	95	81
Totals	7 varieties	304	302	1,313	

number of lateral (side) roots. This symptom is not confined to attacks by curly-top virus only. The same symptom frequently appears in plants infected with strains of California and New York aster-yellows viruses.

If roots of such plants as beets infected with curly-top virus are cut in cross or longitudinal section, typical brown-black discolored areas in the region of the food-conducting vessels or phloem, as noted previously for stems, will be found (Plate I, C, D). This is not a typical symptom in all plants, however, and is characteristically absent in cantaloupe, honeydew melon, and watermelon roots. Some strains of curly-top virus become localized in roots.

Roots in advanced stages of curly-top virus infections decay and disintegrate.

HOW CURLY-TOP VIRUS IS SPREAD

So far as is known, strains of curly-top viruses are not spread (transmitted) mechanically in the field. Although curly-top virus strains are not known to occur in true seeds, transmission through seed pieces from infected potato tubers has been reported by Giddings (14).

Strains of curly-top virus are spread from diseased to healthy susceptible plants in Arizona by means of the sugar-beet leafhopper, *Circulifer tenellus* (Baker)

Plate IX. — At left is a curly-top virus infected chili pepper showing leaf symptoms as well as a single distorted fruit (at arrow). At right, healthy non-infected plant.

(Plate VIII, C). This insect is the only known carrier (vector) of curly-top virus. Several generations or broods of the sugar-beet leafhopper occur each season in the State. The number of individual insects in flight at any one time may be tremendous. Fortunately, not all of the individual leafhoppers in any one brood necessarily carry curly-top virus.

The sugar-beet leafhopper thrives on wild vegetation in the desert, riverbottoms, or foothills during periods unfavorable for crop plant growth. The insects then migrate into areas under cultivation during the height of the growing season. This is particularly true after vegetation in the desert, riverbottoms, and foothills has become dry.

Like other plant viruses, strains of curly-top virus require some sort of wound or natural opening in order to enter a healthy plant. This wounding is provided by the leafhopper mouth parts during the course of feeding.

In transmitting the virus, the mouth parts of the leafhopper are inserted into the virus-infected plant tissues. They eventually find their way to the food-conducting or phloem regions. It is from the phloem that the leafhopper acquires the virus (acquisition feeding). The greatest concentration of curly-top virus is in the phloem, and the mouth parts of the leafhoppers are well adapted to transmission.

The leafhopper mouth parts are eventually withdrawn from the infected phloem of the plant and the insect moves on. After some time, subsequent to acquiring virus, the viruliferous leafhopper again inserts its mouth parts into the phloem of a healthy, curly-top virus susceptible plant. The virus is then discharged into the

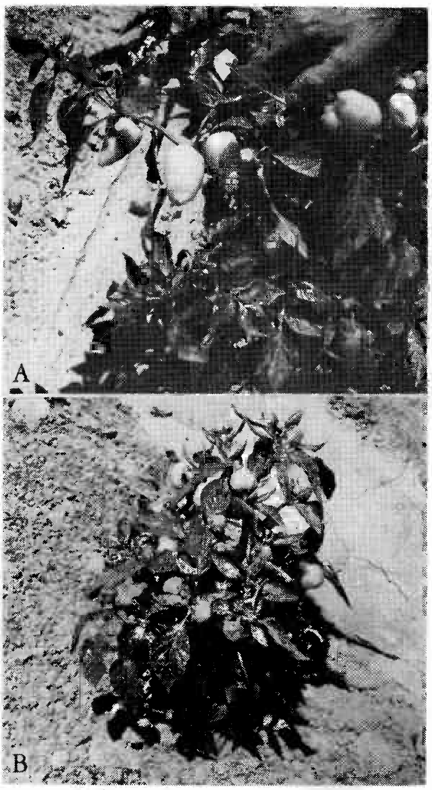

Plate X. — Healthy and curly-top virus infected Floral Gem pepper. A. Non-infected plant showing the fruits in normal position. B. Curly-top virus infected plant showing upright position of fruits and the stiff appearance of the entire plant.

Plate XI. — Symptoms caused by curly-top virus in Summer Crookneck Squash. The leaves are much distorted and the fruit is stunted and twisted. The size of the fruit is much reduced.

healthy tissues and infection is accomplished. In from seven days to two weeks after infection, a susceptible plant will exhibit typical symptoms of curly-top virus invasion.

Some of the general factors concerned with the transmission of curly-top virus strains are depicted in Figure 4.

Sugar-beet leafhoppers may acquire curly-top virus from several sources, including: (a) feedings on infected weeds in the over-wintering areas, such as the desert, riverbottoms, or foothills, previous to spring migrations into the vegetable-growing regions, and (b) feedings on diseased crop plants, ornamental plants and weeds, after the spring migrations have taken place (See Fig. 4).

The time required for a leafhopper to acquire virus from a curly-top diseased plant may be as little as one minute (2). Later on, after a lapse period, a leafhopper may cause infection in a healthy plant in as little as one minute, according to Bennett (2).

Regardless from what sources curly-top virus is acquired by sugar-beet leafhoppers, a period of association of virus with insect must elapse from the time a leafhopper picks up the virus (becomes viruliferous through acquisition feeding) until that same insect is able to cause infection (becomes infective) to a healthy susceptible plant. Since this "lapse period" appears to be necessary for a leafhopper to become infec-

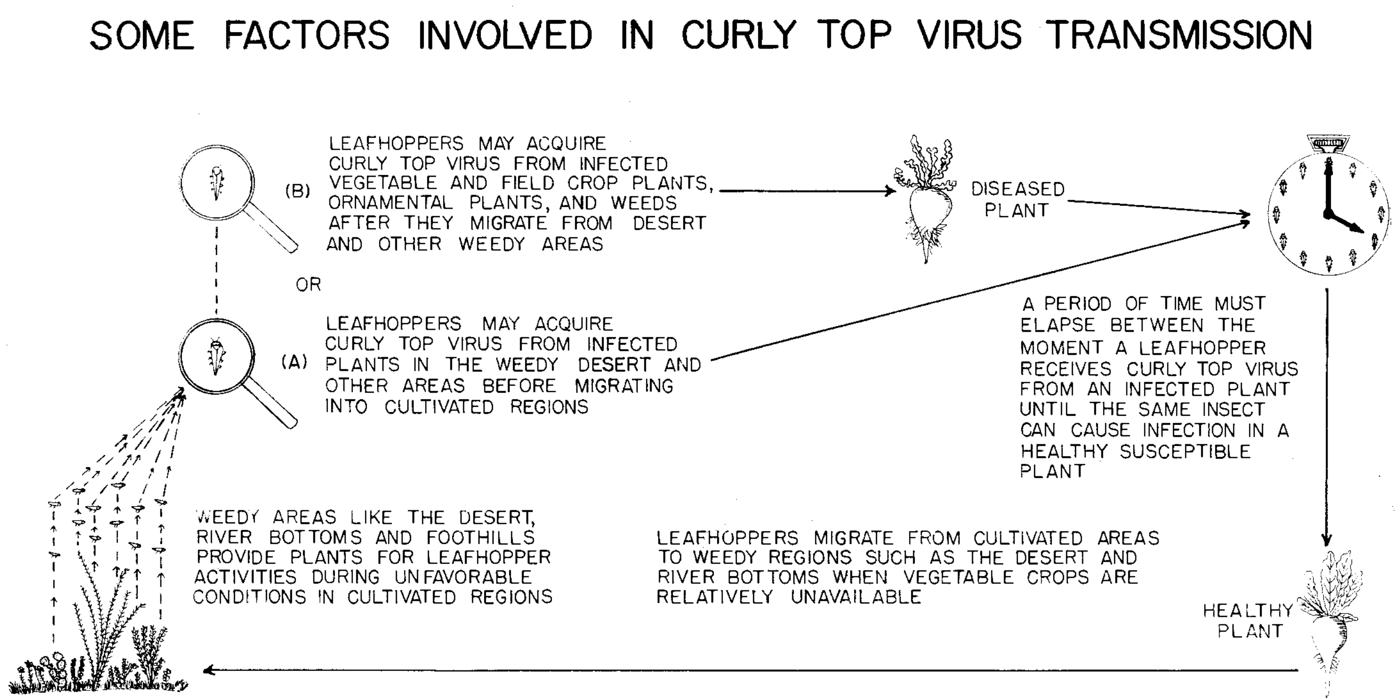

Figure 4. — Diagram illustrating some of the factors which are involved in spread of curly-top virus strains in Arizona. (Further explanation in text).

tive, it is possible for the insect to act as a carrier of virus within its body for some time previous to the infection of a healthy plant. This lapse period may be as short as a few minutes, but is generally not less than four hours, and is frequently longer.

Viruliferous and infective leafhoppers show no external symptoms of virus infection during the lapse period. In this respect, the sugar-beet leafhopper itself acts as a symptomless carrier of curly-top virus. This phenomenon only adds to the difficulties encountered in plant virus disease investigations.

Once leafhoppers become infective after the lapse period, they may remain so for variable periods of time. The length of the infective period depends on the individual leafhopper. Some leafhoppers remain infective for many hours; others are infective throughout their entire life cycle. In any event, once infective after the lapse period, leafhoppers are able to infect a great many healthy but curly-top virus susceptible plants without access to additional sources of virus in diseased specimens. Giddings (10) asserts that his investigations in California show that only small percentages of sugar-beet leafhoppers are carrying highly active virus when they migrate from the winter breeding desert areas into the cultivated regions. Upon migration into cultivated areas, the percentages of insects carrying highly infective virus increase tremendously. By the end of a growing season, Giddings (10) states, the percentages of leafhoppers carrying highly infective virus may reach 80 or 90.

CONTROL OF CURLY-TOP

No methods have been devised to eliminate curly-top virus from plants once infection has taken place. It is also virtually impossible to prevent infections of susceptible plants. Severity of attacks have been lessened in specific crops in certain areas by the adoption of one or more measures which tend to eliminate potential sources of virus. For example, the elimination of susceptible weeds and ornamental plants which favor the activities of the leafhopper vector and which may also be harboring the virus, frequently aids in reducing losses from the disease.

Frequently, mild attacks of curly-top virus in such vegetables as tomatoes result in insignificant damage to the final crop. In these cases, the virus attack is obviously weak, and plants may escape any further inroads of the disease.

Resistant Varieties

Varieties of plants resistant to curly-top virus attacks are few in number. Some of the plants which have been developed for their resistance are not adaptable to local conditions of culture. Usually, seed of resistant varieties are available in the open market from reputable dealers. Wherever practical, resistant varieties should be used.

Cultivation of certain varieties of plants showing some resistance to strains of curly-top virus has been the basis for fairly satisfactory control of the disease in some instances. This is particularly true with sugar beets, several varieties of which have been developed for their resistance to infection. Giddings (9) asserts that resistant varieties of sugar beets show less curly-top injury than varieties such as Old Type. This is true even in the early stages of development (9). In melons, Hills and Taylor (17) found that cantaloupe plants become more resistant to curly-top virus infection as they approach a 6-leaf to maturity stage.

Marblehead Squash was developed for its resistance to curly-top virus. Infections in some resistant varieties of both beets and squash will take place, but the infected plants show only mild symptoms and go on to produce an acceptable product.

As is the case with many other viruses, including the mosaics, some varieties of plants showing resistance to curly-top over long periods of time suddenly lose their resistance and succumb to severe infection. This has happened in the case of some of the so-called resistant sugar beets. Breakdown in resistance is sometimes the result of the origin of a new strain of the attacking virus and at other times merely a constitutional change in the resistant plant itself.

Of interest in connection with varieties of plants resistant to curly-top virus are the fiindings of Giddings (10) who showed that fewer sugar-beet leafhoppers from resistant sugar beet varieties are apt to be carrying curly-top virus than are those from nearby susceptible varieties. This emphasizes the desirability of utilizing resistant varieties.

Sanitation

Numerous ornamental plants and weeds serve both for the biological activities of the leafhopper vector of curly-top virus *(Circulifer tenellus)* as well as reservoirs for the virus itself. The various ornamental plants and weeds attacked by the virus are too numerous to be recorded here.

Undoubtedly, the elimination of susceptible ornamental plants and weeds from within and surrounding a crop to be protected from curly-top virus attack will aid in reducing the attraction for the sugar-beet leafhopper. Destruction of weeds will also eliminate virus which may be present in them. Weeds, in particular, should also be eliminated from all areas near the crop fields. Volunteer susceptible crop plants which may appear in a planting from a previous crop should also be destroyed. Volunteer crop plants from a previous crop can create considerable hazard to a new planting (Plate XII, A). Too often weeds along ditchbanks, fence-rows, and highways are properly eradicated while inroads of volunteer susceptible plants in new plantings are overlooked.

In the example illustrated in Plate XII, cantaloupes which are highly susceptible to curly-top virus attack have followed a planting of sugar beets. The latter are not only susceptible to the virus, but are an excellent host plant for the sugar-beet leafhopper which transmits the virus. As illustrated in Plate XII, volunteer infected sugar-beet plants have appeared in the beds and furrows of the cantaloupe planting. Not only do such infected beet plants aid in supplying virus for cantaloupe infection, but also for the infection of nearby weeds. Some of the weeds will carry the virus over during periods unfavorable for the growth of crops until the following season. Such weeds serve as reservoirs from which subse-

Plate XII. — Some of the hazards to be expected with improper crop rotation. At (a) is a curly-top infected sugar-beet plant — a volunteer leftover from a previous crop. The runners of a cantaloupe vine are shown at (b). Cantaloupes are also very susceptible to curly-top virus. Permitting volunteer plants to grow in the main crop area may lead to high percentages of infections (Further explanation in text).

quent curly-top virus spreads may occur during the following season. They also serve to increase the potential virus spread into the current crop.

It is obvious from the foregoing discussion that in the general crop rotation program, curly-top virus susceptible plants should not follow each other. This is particularly so where the same planting areas are involved and where the same weed varieties may be expected to be present year after year.

Time of Planting

In some local areas where climatic conditions permit, the principal leafhopper migrations may be partially avoided by advancing or delaying dates of plantings. Such practices will, of course, be more effective in areas isolated from the main crop-producing regions. The necessity for "making" certain favorable marketing periods will determine whether this type of protection from curly-top virus attack is feasible. In most of the irrigated areas of Arizona, the scheduling of plantings designed to avoid the main leafhopper migrations is virtually impossible because of the number of leafhopper migrations and tremendous sources of virus in crop plants, weeds, and ornamental plants. Curly-top virus infections take place in the field in Arizona over considerable periods of time. In some areas infections occur rather early in a season; in others, late. Late infections are typical of the Yuma district. Curly-top infected tomatoes have been observed in the Yuma area in December.

The main consideration in time of planting is that in some areas plantings of sugar beets and melons can be made sufficiently early so that by the time viruliferous leafhoppers are migrating, the plants have developed some resistance.

Sticky board traps (18, Plate XIV, A, B) indicate that the sugar-beet leafhopper itself may be in flight at almost any time of the year in southern Arizona. In addition, length of the growing season in itself aids in the prevalence of vector and virus over considerable periods of time. Hence, dates of plantings are generally ineffective controls in Arizona, but have been effective elsewhere.

Barrier and Trap Crops[5]

Certain crop or ornamental plants not susceptible to curly-top virus strains, if planted in a manner surrounding a crop to be protected, could conceivably serve as barriers to discourage the inroads of migrating leafhoppers. On the other hand, crops susceptible to curly-top virus might be used in a similar way in order to trap and absorb some of the initial virus discharged by migrating leafhoppers.

According to experiments conducted at the Arizona Agricultural Experiment Station, Tucson, both barrier and trap crops are effective in protecting a main crop only during seasons when the presence of curly-top virus in leafhoppers is low. The effectiveness of either barrier or trap crops could be increased by isolation of the main planting. Alfalfa surrounding tomatoes was effective in some experiments. This is rather odd in view of the fact that alfalfa itself is a field crop susceptible to curly-top virus attack. Nearness of alfalfa could be a detriment in the case of mosaic viruses because this field crop is an excellent source for the aphids which are the carriers of mosaic viruses.

Closely spaced non-susceptible plants, such as corn, around tomato plantings were ineffective in reducing the severity of curly-top virus during seasons when viruliferous leafhoppers were prevalent.

It is obvious that the effectiveness of either barrier or trap crops depends to a large extent on the prevalence of the virus.

Insecticides

The use of an appropriate insecticide against the sugar-beet leafhopper in Arizona is of questionable value, because of the many breeding areas of the insect and general prevalence of curly-top virus. If insecticides are used, they should be applied not only to the crop to be protected, but also to surrounding susceptible crops, ornamental plants and weeds. As with other methods recommended for reducing the severity of attack of curly-top virus, local conditions will determine the value

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[5]Barrier crop is used in the sense of a physical barrier discouraging leafhopper movements.

Trap crop is one on which the insects would feed and discharge virus before entering the main planted area.

of specific measures selected as compared with the expense involved and other factors.

Specific recommendations for an insecticide to be applied to any particular crop should always be sought from entomologists or your County Agricultural Agent.

Considerable success in alleviating losses from curly-top virus in California-grown tomatoes and other plants has been achieved through the use of appropriately timed applications of insecticidal sprays in the foothill and other activity areas of the sugar-beet leafhopper vector (1). This has been particularly true in the San Joaquin Valley of California. The spray utilized has been DDT in diesel oil, applied as an aerosol, at a rate of 1 pound actual in 2 gallons of oil, for each acre (1). Applications have been made both from the air and with ground equipment.

This unique but costly approach to curly-top virus control has been effective against the egg, young and adult stages of the leafhopper. The sprays are applied at intervals during the period November 1 to April 20, the timing depending on the cycle of the leafhopper and the variations in climatic conditions. In some years, when winter rains come early or late, the program has either been altered or the results have been less outstanding. According to reliable appraisals, the expense involved in this undertaking is fully justified in view of the value of the crops protected and the effectiveness in reducing populations of leafhoppers.

One of the spray periods occurs in the late summer or fall when adult leafhoppers have returned to the foothills from the vegetable-growing areas and are concentrated on perennial weeds. Another spraying takes place between December and February after winter rains have encouraged the development of filaree, pepper grass, *Plantago*, etc. The leafhoppers move from the perennial weeds to these hosts, thereby becoming concentrated on the canyon floors.

During March and April, the leafhoppers move from the canyon floors to the low foothills, particularly to areas having warm southern exposures. Since the leafhoppers are once more concentrated in specific areas, their numbers can be reduced. It is in the foothill areas that the spring or "flight" generations are produced. These flights complete the cycle when leafhoppers once more move into the valleys and the huge vegetable-growing acreages. According to Armitage (1), these spring flights of the sugar-beet leafhopper may extend as much as 80 to 120 miles in a single night. The leafhopper flights move progressively from south to north during the migrations from the foothills into the vegetable-growing areas. The movement back to the foothills from the vegetable-growing areas is progressively north to south.

Delay in plantings until the spraying schedule is over on April 20 has also aided in reducing losses from curly-top virus in the San Joaquin Valley of California, according to Armitage (1). This delay is possible with the exception of early table tomatoes which must meet a specific market.

Other Recommendations

Spacing of hills — For tomatoes it has been suggested by various investigators elsewhere that close spacing of hills, as well as the retention of several plants per hill, afford conditions which are not attractive to the sugar-beet leafhopper. As a result, less curly-top will occur. The basic idea in these suggestions is to increase the number of plant hairs within a given unit area, a situation which causes the legs of the virus-carrying leafhoppers to become entangled.

Experiments have been conducted for the past four years at the Arizona Agricultural Experiment Station, Tucson, to test this idea. No particular benefits from close spacing with numerous plants per hill in several tomato varieties have been noted except where plants have been tied to stakes. The effect of staking is to bring the stems and leaves of several plants in a hill closer, thus affording a high concentration of hairs in a small area. In cases where plants have not been tied to stakes, no benefits from close spacing of hills were noted, as plant stems and leaves tend to fall away in the furrows. Where closely spaced hills with several plants per hill were protected by cages consisting of fine-mesh wire or cheesecloth, control of curly-top was quite evident.

Screening of plants against leafhopper attacks — In small-scale plantings, such as in the home garden, cages consisting of fine-mesh material can be used to surround such plants as tomatoes and thus protect them from feedings of the curly-top virus vector.

In experimental plantings at Tucson, cages of fine-mesh cheesecloth erected to a height of four to four and one-half feet in some cases, in others to five to six feet, gave full protection to tomato plants. In some open cages, closely spaced strings sufficiently short to be in motion in moving air currents were inserted. Only fair control of curly-top resulted.

Best control of the disease was secured in cases where the cages and caged plants were surrounded with a barrier or trap crop such as alfalfa.

If cages are used, they should have a double wall with an intervening space of at least one-fourth of an inch. If double walls are provided, the mouth parts of the leafhoppers cannot reach plants to cause infections. In single-walled cages, plant parts often make contact with the inner surface of the fine-mesh materials. Leafhoppers can feed through the single thickness of the material.

Although caging is obviously practical only on a small scale, some plantings of considerable size of other crops have been protected from other agencies, such as frost, through the use of aster cloth of fine mesh. Early planted tomatoes, squash, and other curly-top susceptible crops could be protected in a similar manner. Single-thickness cloth could be used because the few plants around the edges which might be in contact with leafhopper stylets would be insignificant in the total production picture.

Isolation of the crop — In areas where acreages of crops to be protected from curly-top virus infection are relatively small, isolation of the acreages from other susceptible plants will aid in reducing losses. Isolation alone, without the adoption of one or more additional measures, is seldom effective in "bad" curly-top years when much virus is present. In the case of any isolated planting, sanitation and other control measures should also be adopted.

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APPENDIX

TABLE 2. — Susceptibility of Arizona vegetables to strains of curly-top virus. Reports up to and including July 1, 1955.

Vegetable	Curly-top reported	Vegetable	Curly-top reported
Artichoke,	-	Leek	-
Asparagus	-	Lettuce, Head	-
Bean, Bush	*	Lettuce, Leaf	-
Bean, Pole	*	Muskmelon	*
Bean, Lima	*	Mustard	-
Bean, Soya	-	Okra	-
Beet, Garden	*	Onion	-
Beet, Sugar	*	Parsley	-
Broccoli	*	Parsnip	-
Brussels Sprouts	-	Peas	-
Cabbage, Green	*	Peanuts	-
Cabbage, Chinese	-	Pepper, Bell	*
Cantaloupe	*	Pepper, Chili	*
Carrot	-	Potato, Irish[6]	*
Cauliflower	*	Potato, Sweet	-
Celery[6]	*	Pumpkin	*
Chard	*	Radish	-
Corn, Sweet	-	Rhubarb	-
Cucumber	*	Rutabaga	-
Eggplant	-	Salsify	-
Endive	-	Spinach	*
Garlic	-	Squash, Summer	*
Honeydew	*	Squash, Winter	*
Horseradish	-	Tomato	*
Kale	-	Turnip	*
Kohlrabi	-	Watermelon	*

*Reported in Arizona
-Not reported in Arizona
[6]Field infection reported elsewhere

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