Yellow Wilt of Sugar Beet[1]

C. W. BENNETT, F. J. HILLS, R. EHRENFELD K., J. VALENZUELA B. AND C. KLEIN K.[2]

Received for publication January 17, 1967

Introduction

Yellow wilt is potentially the most destructive disease known to sugar beet. It occurs at the present time only in Argentina and Chile, but, with modern methods of transport, it could easily be introduced into any of the other sugar beet producing areas of the world. If introduced, it probably would be destructive in any semiarid or irrigated area where suitable hosts for the vector and virus are available.

The disease, first discovered in Argentina more than 30 years ago, has been known in Chile since 1945. Studies of yellow wilt have been made in Chile by the Industria Azucarera Nacional S. A., in cooperation with other agencies, over a period of several years. As a result of this work, a considerable amount of information regarding the disease and its potential for destruction has been accumulated. It is the purpose of this report to present the information on yellow wilt now available with the hope that it may be of value in stimulating further investigations on the nature and control of this important disease.

History of the Disease

The origin of yellow wilt is unknown, but it probably was first observed by Henderson (5)[3] who reported that a disease, causing sudden wilting and death of plants, destroyed all of the experimental plantings of sugar beets at the Experiment Station of Rio Negro, near General Roca, Argentina, in 1926-27. A sugar factory was being built at that time in the lower Rio Negro Valley of Argentina. It began operations in 1929. Yields of beets were low both in this area and in the Rio Colorado Valley about 90 miles to the north, apparently caused largely by wilting and death of plants.

In 1937-38 and 1938-39 yellow wilt reached a peak of severity in the plantings of the Rio Negro Valley and was responsible

[1] The research reported in this paper was supported by funds granted under U. S. Public Law 480.

[2] Respectively: Plant Pathologist, Collaborator, ARS, USDA; Extension Agronomist, University of California; Ing. Agrónomo, Industria Azucarera Nacional. S. A.; Ing. Agrónomo, Instituto de Investigacionos Agropecuarias; Student, University of Chile.

[3] Numbers in parentheses refer to literature cited

for almost complete loss of the crop in both years. In 1939-40 and 1940-41 sugar beets were grown in the Rio Negro Valley only on an experimental scale, and in 1941 sugar beet culture in the area was discontinued.

Studies in 1941 in the Rio Negro Valley, and in the United States with diseased beets from the Rio Negro Valley, indicated that yellow wilt is caused by a virus transmitted by a leafhopper described as new by Beamer (1) under the name *Atanus exitiosus* (2).

With the collapse of sugar beet growing in Argentina in 1941, nothing further was heard of yellow wilt until 1945 when the disease appeared in experimental plantings in Chile. It has been present in beet fields each year since the establishment of a sugar beet industry in that country, and has limited the commercial production of sugar beets to areas of Chile south of Talca in which conditions are less favorable for perpetuation and spread of the disease. Even in the areas of commercial beet production, yellow wilt may cause substantial damage in the northern zone of production. Heavy damage has occurred in fields near Parral, especially in the area west of Linares. Large numbers of leafhoppers have been found near Chillán, 60 miles south of Linares, and filaree plants showing typical symptoms of yellow wilt were found in that area in 1966.

Symptoms of the Disease on Sugar Beet

Yellow wilt usually makes its appearance in beet fields only after the plants have attained appreciable size and the roots are more than 2 cm in diameter. There may be a wide range of symptoms from stunting and yellowing through wilting and rapid collapse of the plant. Two distinct sets of symptoms have been described as the Yellowing Phase and the Wilting Phase (2).

Yellowing Phase Yellowing of infected plants, without marked wilting, may occur early in the season or in areas where temperatures and transpiration rates are relatively low. First symptoms consist of dwarfing, yellowing, and downward turning of the tips of young leaves (Figure 1). Leaves half-grown at the time the very young leaves begin to show symptoms may have yellow sectors, or they may show general yellowing often accompanied by necrosis. As the plant develops, new leaves are dwarfed, yellowed, and stunted and the leaf blade tends to be narrow or strap-like. There is a tendency for growth and development of axillary buds and the plant may become markedly rosetted. After first symptoms appear, root growth is greatly retarded. Tips of many rootlets die, and this is followed by the development of lateral rootlets, which in turn die, resulting in the production of tufts of rootlets with restricted range of soil penetration.

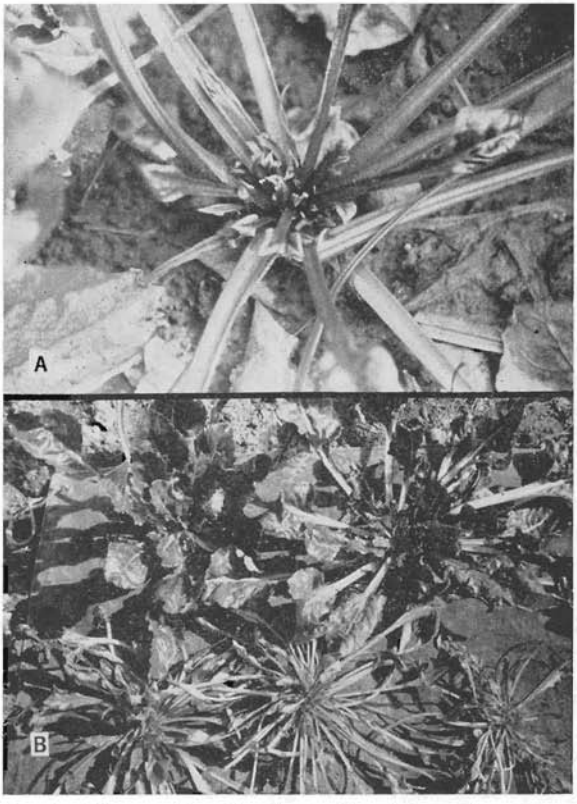

Figure 1.—A. Plant of table beet showing early symptoms of the yellowing phase of yellow wilt. New leaves are numerous and dwarfed, and tips of leaves tend to turn downward. B. Sugar beet plants; upper left, healthy; upper right, recently infected, new leaves dwarfed; lower three plants showing later stage of yellowing phase of disease. Leaf blades are strap-like and plants have become rosetted.

Larger veins of some of the leaves of affected plants may show a distinct type of chlorosis that extends slightly into adjacent parenchyma (Figure 2A). Exudate, probably from the phloem, has been observed as droplets of liquid along the veins of some of the leaves that showed first symptoms. In some cases, also, water-soaked areas adjacent to larger veins were observed; this probably resulted from the seepage of phloem content into the intercellular spaces of the parenchyma (Figure 2B).

Plants infected after the roots have attained considerable size, may show symptoms only on one side in the earlier stages of disease development, indicating introduction of virus through a single leaf and slow lateral invasion of the crown of the plant by the virus.

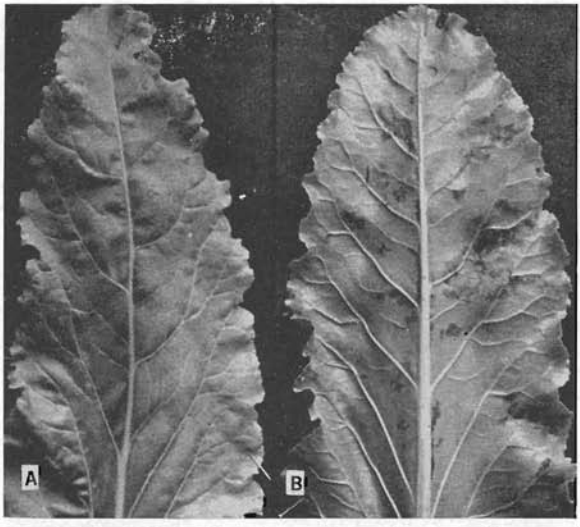

Figure 2.—A. Beet leaf showing vein yellowing characteristic of the yellowing phase of yellow wilt. B. Beet leaf showing water-soaked areas indicating leakage of phloem content into intercellular spaces sometimes found in the early stages of development of the wilt phase of the disease.

Wilting Phase In mid-season or under conditions of high temperature and low humidity, plants infected with the yellow wilt virus may wilt and die within a few days without showing specific top symptoms other than wilting (Figure 3). When the tops begin to wilt, however, tips of the main roots have already become shrunken and flaccid. The shrinking and softening of the root may progress upward until the entire root is involved. The root usually shrinks to such a degree that it may be readily removed from the soil. Rot-producing organisms soon begin to cause decay and the entire root may collapse into a rotted mass. Some plants that wilt and lose most of their mature leaves sometimes recover to an appreciable degree. Such plants may live for a considerable time and continue to grow slowly if the roots are not too badly damaged by root-rot organisms.

Conditions that Influence Type of Symptom Expression The yellows phase of the yellow-wilt disease is so different from the wilt phase that a question has been raised as to whether the two types of symptom expression may not be caused by different agents. The evidence, however, indicates strongly that both yellowing and wilting are caused by the same virus. Plants showing early stages of wilt in the field in Argentina in 1941 showed only the yellowing phase when transferred to the greenhouse in Arlington, Virginia, and transmission of virus from these plants by

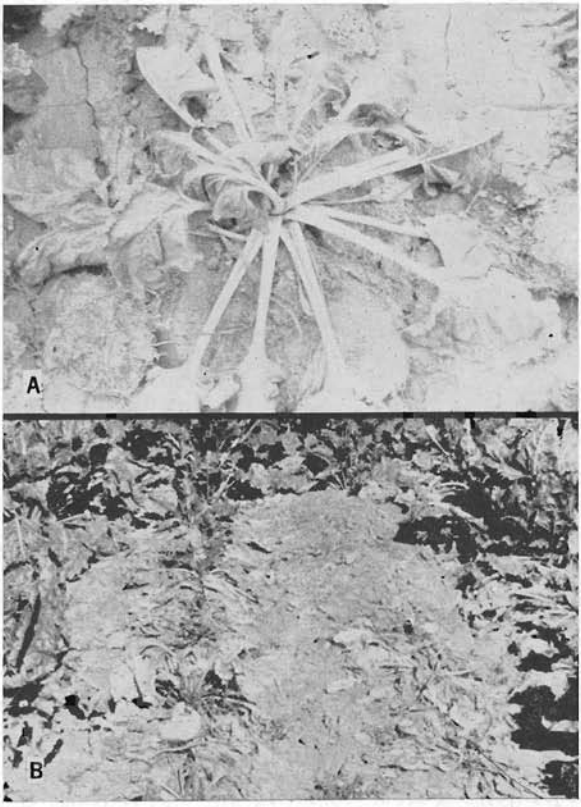

Figure 3.—A. Sugar beet plant showing beginning of the wilt phase of disease, and B, sugar beet plants showing more advanced stages of deterioration.

means of graft and dodder produced only the yellowing phase (2). Ehrenfeld K. (4) obtained similar results from wilted plants transferred from the field to the greenhouse in Chile.

It may be significant that the wilt phase of the disease appears under conditions of high temperature and low humidity, whereas the yellowing phase appears under conditions of lower temperature and higher humidity. It seems probable that infected plants suffer an initial shock that drastically decreases their ability to take up water. If transpiration rates are high during this acute stage of the disease, plants wilt and die. However, if transpiration rates are low during the acute stage of the disease, infected plants partially recover and pass into a chronic stage of disease in which they are free to express typical yellowing symptoms.

Transmission

The yellow wilt virus has been transmitted by two species of dodder, *Cuscuta californica* Choisy and *C. campestris* Yunck., and by graft, but not by juice inoculation (2, 4).

Evidence was obtained in field tests in the Rio Negro Valley of Argentina in 1941 that the yellow wilt virus is transmissible by a leafhopper, *Paratanus exitiosus* (Beamer) (*Atanus exitiosus* Beamer) (2). Ehrenfeld K. (4) also reported transmission of yellow wilt virus on sugar beet by means of *P. exitiosus* in field tests in Chile in 1961, and in 1964 the disease was transmitted in greenhouse tests by *P. exitiosus* (8).

Greenhouse Tests with *Paratanus exitiosus*

In 1966, tests were made at the La Platina Station of the Instituto de Investigationes Agropecuarias, near Santiago, Chile, to obtain further information on the ability of *P. exitiosus* to transmit yellow wilt virus under more rigidly controlled conditions in a screened greenhouse.

In preparation for these tests, leafhoppers were collected from sugar beet plots in the vicinity of the Station and placed on diseased and healthy sugar beet plants in breeding cages. The leafhoppers multiplied readily on sugar beet under greenhouse conditions and provided an abundance of nymphs and adults for experimental use.

First transmission tests were made by placing leafhoppers in small leaf cages and allowing the insects to feed for a period of 7 days. Transmission was obtained on sugar beet in four of five tests (Table 1). The percentage of infection was low, averaging only 14%. The incubation period of the disease in the inoculated plants ranged from 24 to 30 days. This long incubation period may account, at least in part, for the fact that the disease is rarely found on small beet plants in the field, since with an

Table 1.—Transmission of yellow wilt virus to seedling sugar beet plants by means of the leafhopper, *Paratanus exitiosus*.

Test	Leafhoppers used per plant	Plants infected and inoculated[1]	Infection
Number	Number	Number	Percent
1	2 to 4	3/38	7.9
2	4	4/7	57.1
3	10	1/15	6.7
4	10	3/16	18.8
5	5	0/4	0
Totals		11/80	13.8

[1] The numerator indicates the number of plants infected; the denominator the number of plants inoculated.

incubation period of this length, even plants infected in the cotyledon stage could reach appreciable size before showing symptoms.

Influence of Numbers of Insects on Infection After preliminary tests indicated that *P. exitiosus* might be an inefficient vector, a test was made to determine whether infection increased with increased numbers of vectors per plant. In this test, 1, 3, 5, and 10 (5 in each of 2 cages), respectively, were placed on seedling sugar beet plants in leaf cages, and allowed to feed 7 days.

The results (Table 2) indicate that an increase in the number of leafhoppers per inoculated plant gave an increased percentage of infection. However, even with 10 leafhoppers per plant, only 26.6% infection was produced.

Table 2.—Infection of sugar beets with yellow wilt virus by means of different numbers of adult viruliferous leafhoppers (*Paratanus exitiosus*).

Adult leafhoppers per plant	Plants infected and inoculated[1]	Infection
Number	Number	Percent
1	1/32	3.1
3	2/32	6.2
5	4/32	12.5
10 (5 in each of 2 cages)	8/30	26.6

[1] The numerator indicates number of plants infected; the denominator the number of plants inoculated.

Similar low percentages of infection were obtained with one or two leafhoppers per plant with other species of plants that later proved to be susceptible to infection. Under the conditions of these tests, it appears that 20 to 50 leafhoppers per plant may be required for production of reasonably high percentages of infection.

Effect of Size of Inoculated Plant on Infection The low percentages of infection of inoculated cotyledon-size sugar beet plants in previous experiments suggested that age of plant might influence percentage of infection and that perhaps plants might increase in susceptibility with age. A test was made, therefore, in which 2 viruliferous leafhoppers were caged on plants in the cotyledon stage, 2 true-leaf stage, 6 true-leaf stage, and on plants with roots about 2 cm in diameter.

Although the numbers of plants tested were limited, it would appear from the results (Table 3) that size of plant had little or no effect on susceptibility to infection.

Table 3.—Effect of size of inoculated sugar beet plants on susceptibility to yellow wilt infection.

Stage of plant growth	Plants inoculated and infected[1]	Infection
	Number	Percent
Cotyledons only	2/15	13.3
2 true leaves	2/12	16.5
6 true leaves	4/13	30.8
Root 2 cm in diameter	1/5	20.0

[1] The numerator indicates number of plants infected; the denominator the number of plants inoculated.

Other Possible Vectors of the Yellow Wilt Virus

The results of experimental tests have given abundant evidence that *Paratanus exitiosus* is a vector of the yellow wilt virus, although evidence thus far indicates that it may be a relatively inefficient one. Whether there are other vectors of this virus remains to be determined. Tests with the green peach aphid, *Myzus persicae* (Sulzer), and with a species of *Empoasca* common on sugar beets in the Santiago area, indicate that neither of these insects is able to transmit the yellow wilt virus. However, there are several species of *Paratanus*, other than *P. exitiosus*, that need to be tested.

In a revision of the neotropical species of leafhoppers published in 1959, Linnavuori (6) lists the following species of this genus as occurring in South America:

Paratanus exitiosus (Beamer); Argentina and Chile
Paratanus inermis Linnavouri; Argentina
Paratanus magniceps Linnavouri; Argentina (Closely related to *P. exitiosus*, but more robust)
Paratanus psidii Linnavouri; Venezuela
Paratanus rotundiceps Linnavouri; Argentina
Paratanus wygodzinski Linnavouri; Argentina
Paratanus yusti Young; Ecuador

It is possible, and even probable, in the light of known relationships of other viruses of the yellows type to their leafhopper vectors, that species closely related to *P. exitiosus*, may prove to be vectors of the yellow wilt virus. Little is known regarding the distribution and population levels of any of these species other than *P. exitiosus;* but in fairly extensive sweepings of beet plots and fields in the Mendoza province of Argentina and in Chile in 1966, *P. exitiosus* was the only species of *Paratanus* captured. Apparently no species of the genus occurs at present in North America.

Host Range of the Disease

Under field conditions yellow wilt has been identified with certainty on sugar beet, table beet, fodder beet, Swiss chard, red-stem filaree (*Erodium cicutarium* (L.) L'Her., and white-stem filaree (*E. mochatum* (L.) L'Her.). It no doubt occurs at times on certain other crop plants and on a number of other common weeds.

Tests were made to determine the susceptibility of readily available species of plants to infection under greenhouse conditions by inoculating plants by means of *Paratanus exitiosus* from colonies on infected sugar beet plants. In the first tests, small numbers of leafhoppers were placed in leaf cages and allowed to feed 7 days on seedling plants. After it was found that infection by this method of inoculation was very low, even on sugar beet, later inoculations were made by placing large numbers of leafhoppers (20 to 50) on individual plants in large plastic cages, or in large breeding cages, and allowing them to feed for prolonged periods.

By this method of inoculation, symptoms having essentially the same characteristics as yellow wilt as it occurs on sugar beet in the field, were obtained on *Amaranthus retroflexus* L. (redroot amaranth), *Beta vulgaris* L. (sugar beet), *Chenopodium capitatum* (L.) Asch. (strawberry blite), *C. murale* L. (nettle-leaf goosefoot), *Claytonia perfoliata* Donn. (miner's lettuce), *Datura stramonium* L. (jimson weed), *Erodium cicutarium* (L.) L'Her (red-stem filaree), E. *moschatum* (L.) L'Her. (white-stem filaree), *Hyoscyamus niger* L. (black henbane), *Lycopersicon esculentum* Mill. (tomato), *Nicotiana bigelovii* S. Wats. (Indian tobacco), *N. clevelandii* A. Gray, *Spinacea oleracea* L. (spinach), *Stellaria media* (L.) Cyrillo (chickweed), *Tetragonia expansa* Murr. (New Zealand spinach), and probably on *Capsella bursa-pastoris* (L.) Medic. (shepherds-purse).

Symptoms on all of these plants had many characteristics in common (Figures 4 and 5). First symptoms consisted of inward and downward rolling of the edges of young leaves, accompanied by dwarfing and distortion and often by yellowing of the larger veins and the margins of the leaves. Growth of the terminals of shoots was markedly retarded and there was a tendency for axillary buds to start growth and to develop into weak, spindling, shoots. Plants of *Chenopodium capitatum* were dwarfed on the side where virus was introduced and red pigment was greatly intensified on the lower side of affected leaves. Leaves of *Claytonia perfoliata* also produced increased amounts of dark red pigment in the distal half of leaves of affected plants.

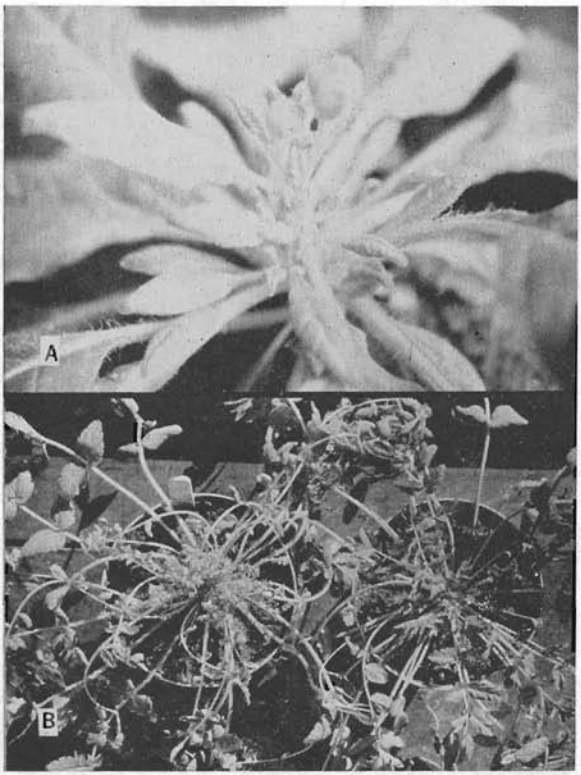

Figure 4.—A. Plant of *Nicotiana bigelovii* showing early stages of yellow wilt. B. Diseased and healthy plants of *Erodium moschatum* (red-stem filaree). The diseased plant shows early stages of dwarfing and rosetting.

Of this group of host plants, it is worthy of note that *Nicotiana bigelovii* and *N. clevelandii* have been found susceptible to infection by all sugar beet viruses with which they have been tested.

Owing to a shortage of time and space and other complications, virus was not recovered from any of these plants, but it seems rather certain that the symptoms observed were caused by the yellow wilt virus, since the symptoms on all affected plants were so similar to those on sugar beets showing the yellowing phase in the field. No evidence of the wilt phase of the disease was noted on any of the diseased plants in the greenhouse.

Vector of Yellow Wilt Virus

It is now evident that the leafhopper, *Paratanus exitiosus,* is a vector of the sugar beet yellow wilt virus. It has been associated with the occurrence of yellow wilt in both Argentina and Chile

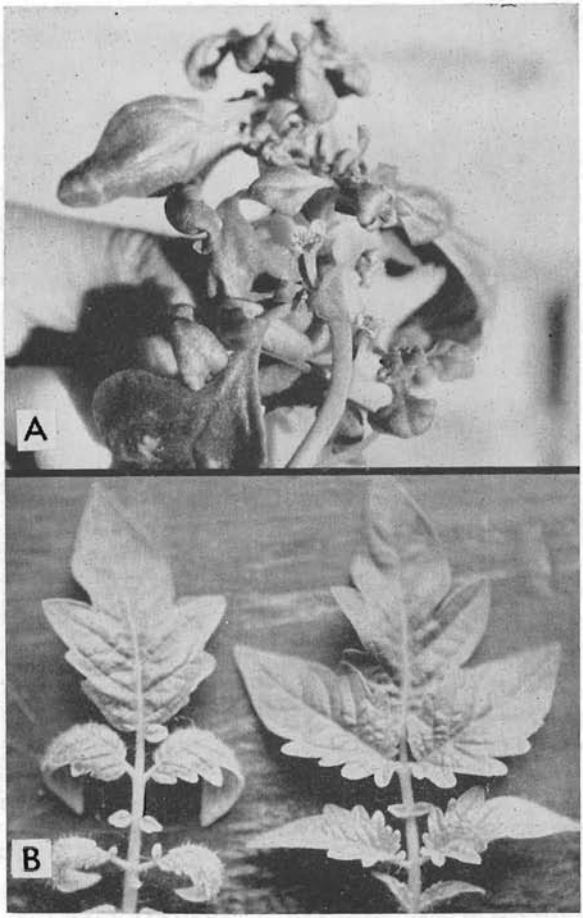

Figure 5.—A. Stem of a plant of *Tetragonia expansa* (New Zealand spinach) showing leaf rolling and dwarfing and elongation of flower pedicels characteristic of yellow wilt on this species. B. Leaves of tomato plants showing downward rolling of edges of leaves of infected plant (left) as compared with healthy leaf (right).

for a number of years and appears to be the principal vector of the yellow wilt virus in all of the areas where the disease has been observed. A considerable amount of information regarding the insect has been obtained during the past few years, but much additional information will be required to supply an adequate knowledge of all of the relationships of this vector to natural spread of yellow wilt. *P. exitiosus* belongs to the same subfamily as *Circulifer tenellus* (Baker), the vector of North American sugar beet curly top virus.

Geographic Distribution As already indicated, *Paratanus exitiosus* had been found only in Argentina and Chile, but appears to be well distributed over most of the more arid agricultural areas of these two countries, although apparently not in high population densities. In Argentina, it is known to extend from the Rio Negro Valley in the south to Mendoza in the north. In Chile, it extends from the province of Bio-Bio northward to Santiago and even to Aconcagua in the central part of the country and in arid coastal areas. It is possible that the distribution of the leafhopper is more extensive than thus far indicated. It has been found mainly where sugar beets have been grown, but large populations have been observed on native vegetation in some areas, especially west of the central valley between Aconcagua and Bio-Bio.

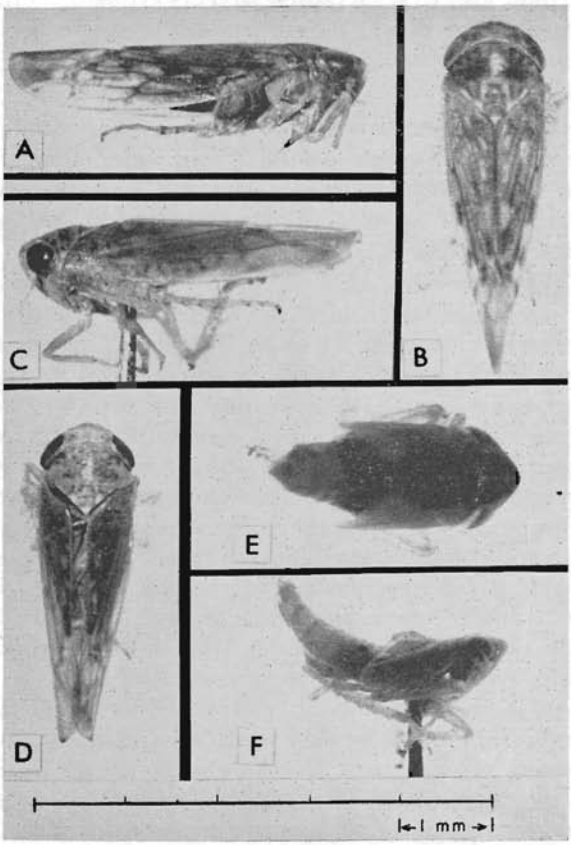

Figure 6.—*Paratanus exitiosus*, the vector of yellow wilt virus. A and C, adult females; B and D, adult males; E and F, nymphs.

Description *Paratanus exitiosus* was described first by Beamer (1) in 1943. Adults are slightly larger than adults of *Circulifer tenellus,* the vector of sugar beet curly top virus. Females are about 3 mm long and 1 mm wide, and males are somewhat smaller (Figure 6. a-d). There is considerable color range both in the field and in breeding cages. Spring and early summer broods are likely to be light brown on the dorsal side and yellow on the ventral side. The yellow color often extends well up on the ventral side of the head. Color changes take place through the summer and fall and many adults, especially females, are dark on the dorsal side and may show no yellow color on the ventral surface. Adults, showing a wide range of color variation, were selected from colonies and from the field and sent to Entomology Research Division of the United States Department of Agriculture in May, 1966, for verification of identification. All were identified by J. P. Kramer as *P. exitiosus.* The observed color variations, therefore, are normal for the species.

The nymphs are creamy white to tan, usually with dark spots of various sizes and shapes on the dorsal side (Figure 6, e & f). They have rather distinct shapes and markings and are readily distinguishable from nymphs of other species of leafhoppers commonly found on sugar beets in fields in Chile.

Life Cycle Females of *Paratanus exitiosus* lay eggs on the surface of leaves or just under the epidermis, usually in groups of two or more lying parallel to each other. On plants unfavorable as hosts, however, eggs have been observed in more or less perpendicular position with only one end attached to the leaf.

Eggs hatch in 10 to 12 days under favorable conditions. Nymphs soon become active and start feeding almost immediately after hatching. They are able to jump an appreciable distance 1 minute after freeing themselves from the egg case. There appear to be five instars and the nymphal stage lasted 44 to 48 days in cages under greenhouse conditions. Adults lived up to 60 days in transfer cages and females lived longer than males. A single female may lay as many as 100 eggs during its life span.

The time required for the production of a single generation under greenhouse conditions is estimated to be 55 to 65 days, but this may vary considerably with environmental conditions. The optimum temperature for development of *P. exitiosus* is estimated to range from 19 to 23°C (7). This is appreciably lower than the optimum temperature range for development of *Circulifer tenellus.* There is evidence that summer temperatures in some areas in which *P. exitiosus* occurs may be too high for

appreciable increase during the summer months. In early April, 1966, nymphs and adults were scarce in beet plots near Mendoza, Argentina, although high percentages of beet plants were dead or dying from yellow wilt, indicating that higher populations of *P. exitiosus* had been present earlier in the season and that populations had declined as temperatures increased. This conclusion is strengthened by the fact that during this same period in plots near Santiago, Chile, where temperatures were lower, the leafhoppers continued to increase throughout the summer and were still abundant through May and most of June. *P. exitiosus* probably is able to reproduce throughout the year at Santiago, where the summer temperatures are not excessively high and the winter temperatures rarely fall below 0°C. Summer populations may be high on beets. Winter populations are much lower, but all stages of the insect, including eggs, nymphs, and adults, have been found on beets throughout the winter months at the La Platina Station, Rinconada-Maipú, and other areas around Santiago.

The most favorable humidity for reproduction of *P. exitiosus* is reported to range from 55 to 85% (8). However, there is considerable question as to the part atmospheric humidity plays in the reproduction of *P. exitiosus*, as well as in the reproduction of other leafhoppers that thrive under semiarid conditions. Both *P. exitiosus* and *Circulifer tenellus* reproduce well in breeding cages in greenhouses where atmospheric humidity approaches saturation. It seems more likely that factors other than atmospheric humidity are responsible, at least in part, for restriction of these insects to regions of low rainfall.

Feeding Habits *Paratanus exitiosus* is somewhat less active in all stages than *Circulifer tenellus*. Nymphs, if undisturbed frequently feed for prolonged periods in one location. Feeding areas are marked by conspicuous, circular, chlorotic, spots that may reach 5 mm in diameter. The chlorosis is produced by a toxin introduced by the insect. In tests with beet leaves, enough toxin was introduced in a feeding period of 1 hour to produce chlorotic spots 1 to 2 mm in diameter in 48 hours. As nymphs continue to feed, chlorotic spots increase in diameter and the centers may become necrotic. There apparently is no difference in the ability of male and female nymphs to produce spotting.

Spotting was produced by nymphs on all species of plants tested, including a number of species on which the leafhopper did not reproduce and on some on which the leafhopper lived only a few days. Large numbers of nymphs may produce considerable injury to a host plant. If spots are numerous they

coalesce and become necrotic and leaves are badly damaged. The injury by the feeding of nymphs adds somewhat to the difficulty of rearing large numbers of leafhoppers in cages.

Spotting is conspicuous also under field conditions on sugar beet and weeds. Often, nymphs can be found by looking for chlorotic spots and observing the lower side of the leaf where the nymphs may still be feeding in the chlorotic areas.

Ability to produce toxin is lost when the insects molt into the adult stage. Large numbers of adult leafhoppers may feed on a plant for extended periods without producing apparent injury.

Both adults and nymphs feed readily on sugar beet and a number of other plants. There is still some question as to the tissues in which they feed most extensively. Like certain other leafhoppers, they leave a sheath of salivary material which marks the path of penetration of tissues by stylets.

Studies were made of the depth of penetration of stylets, as indicated by the sheath material in cross sections of petioles on which large numbers of leafhoppers had fed. A high percentage of all punctures terminated in the parenchyma, but some were found to enter the phloem areas. Punctures of this latter type were found most frequently in the angles of the petioles where the vascular bundles were closer to the surface. Further studies should be made before conclusions are reached, but if this vector feeds extensively in parenchyma, this type of feeding may markedly affect the efficiency of the insect in virus transmission, particularly if the yellow wilt virus has a high degree of restriction to the phloem.

Tests with feeding membranes showed that both nymphs and adults will feed readily through an animal membrane, called Baudruche Capping Skin, and less readily through a type of Parafilm commonly used with aphid feeding. It should be possible to make studies of the properties on the yellow wilt virus by use of feeding techniques commonly used with certain other vectors.

Host Range and Dissemination The extent of the host range of *P. exitiosus* and the importance of different host plants as a source of virus and vectors for infection of field beets, needs much additional attention. The known host range of the vector, however, is already rather extensive. In a P.L. 480 project report in 1964, Vallejo (8) listed the following species on which all stages, eggs, nymphs, and adults, were found under field conditions: *Amaranthus* sp. (pigweed), *Beta vulgaris* (sugar beet),

Chenopodium album L. (lambsquarters), *Cichorium endivia* L. (chicory), *Convolvulus arvensis* (bindweed), *Eragrostis virescens* Presl. (lovegrass), *Erodium cicutarium* (red-stem filaree), *Helianthus annuus* L. (sunflower), *Linaria* sp. (blue toadflax), *Lolium* sp. (ryegrass), *Polygonum aviculare* L. (knotweed), *Portulaca oleracea* L. (purslane), *Solanum* sp. (nightshade), *Picris echioides* (bristly oxtongue), *Stellaria media* (chickweed), *Veronica persica* Poir. (speedwell), *Vicia faba* L. (horsebean) and *Zea mays* (corn).

To obtain further information on the possible host range of *P. exitiosus,* tests were made with several species of plants at the La Platina Station in the fall of 1966. In these tests plants were placed in breeding cages and 20 to 50 female leafhoppers were added.

The results showed (Table 4) that *Beta vulgaris* (sugar beet), *Spinacia oleracea* (spinach), *Erodium cicutarium* (red-stem filaree), *E. moschatum* (white-stem filaree), and *Vicia faba* (horsebean) are excellent host plants. More than 2,000 nymphs, some approaching the adult stage, were removed from a single plant of white-stem filaree 30 days after 20 female leafhoppers had been added, and large numbers of nymphs were produced on the other favorable species.

Several species of Chenopodiaceae, besides sugar beet and spinach, were hosts. These include *Atriplex microcarpa,* which is abundant in the desert areas of southwestern United States, *Chenopodium murale* which is a common weed in practically all areas where sugar beets are grown, and *Salsoli kali* L. (Russian thistle) which is a common weed over much of western United States and Argentina.

Species of Solanaceae were not hosts or were very poor hosts with the exception of *Hyoscyamus niger* (black henbane) which supported a rather high population of nymphs.

Paratanus exitiosus was found in beet fields examined between Linares and Santiago in Chile during March and April, 1966. Leafhoppers were abundant in a planting near Santiago but less prevalent in fields further south. Leafhoppers were found in all beet plantings examined in the Mendoza area of Argentina in early April. Populations were relatively low, although there was a high percentage of plants affected by yellow wilt in some plantings.

In late summer and fall, leafhoppers were not found in noncultivated areas in Chile and populations on weed plants in cultivated areas were very low. A few leafhoppers were found on

Table 4.—Tests of plants as hosts of *Paratanus exitiosus* under greenhouse conditions.

Plant tested		
Family	Species	Rating as host[1]
Aizoaceae	*Tetragonia expansa* Murr. (New Zealand spinach)	+
Amaranthaceae	*Amaranthus retroflexus* L. (redroot amaranth)	+
Caryophyllaceae	*Stellaria media* (L.) Cyrillo (common chickweed)	0
Chenopodiaceae	*Atriplex coquimbana* Phil.	t
	Atriplex microcarpa (Benth.) Dietr. (Dot scale)	+++
	Atriplex semibaccata R. Br. (Australian saltbush)	++
	Beta vulgaris L. (sugar beet)	+++
	Chenopodium album L. (lambsquarters)	+
	Chenopodium amaranticolor Coste & Reyn.	+
	Chenopodium capitatum (L.) Asch. (strawberry-blite)	+
	Chenopodium murale L. (nettleleaf goosefoot)	+++
	Chenopodium quinoa Willd.	t
	Salsola kali var. *tenuifolia* Tausch (Russian-thistle)	+++
	Spinacia oleracea L. (spinach)	+++
Compositae	*Gomphrena globosa* L.	+
	Helianthus annuus L. (common sunflower)	++
	Lactuca sp. (wild lettuce)	+
	Picris echioides L. (ox-tongue)	+
	Zinnia elegans Jacq. (zinnia)	t
Convolvulaceae	*Convolvulus arvensis* L. (bindweed)	t
	Ipomoea batatas (L.) Lam. (sweet potato)	+
Cruciferae	*Raphanus sativus* L. (radish)	+
Geraniaceae	*Erodium cicutarium* (L.) L'Her. (red-stem filaree)	++++
	Erodium moschatum (L.) L'Her. (white-stem filaree)	+++
Leguminosae	*Melilotus* sp.	++
	Phaseolus vulgaris L. (bean)	t
	Trifolium pratense L. (red clover)	+++
	Vicia faba L. (horsebean)	t++
Polygonaceae	*Rumex* sp. (dock)	t++
Portulaceae	*Claytonia perfoliata* Donn (miner's lettuce)	t
Primulaceae	*Anagallis arvensis* L. (scarlet pimpernel)	0
Solanaceae	*Capsicum frutescens* L. (pepper)	0
	Datura stramonium L. (jimson weed)	0
	Hyoscyamus niger L. (black henbane)	t
	Lycopersicon esculentum Mill. (tomato)	0
	Nicandra physalodes (L.) Gaertn. (*apple-of*-Peru)	0
	Nicotiana bigelovii S. Wats. (indian tobacco)	0
	Nicotiana clevelandii A. Gray	t
	Nicotiana sylvestris Speg. & Comes	+
	Nicotiana tabacum L. (common tobacco)	0
	Solanum tuberosum L. (potato)	0

[1] 0 indicates no nymphs found; t, ++, +++, and ++++ indicate poor, fair, good, and excellent hosts, respectively.

Russian thistle and other weeds in early April near Mendoza in Argentina.

Throughout all of the areas examined in both Chile and Argentina, sugar beet appeared to be the preferred host at the time of year the surveys were made. At the La Platina Station the leafhopper continued to increase through March and April on sugar beet and reached high population levels at harvest time the latter part of April. This increase took place in beets with

large tops which provided a considerable amount of shade. The leafhopper increase in the La Platina planting indicated that *P. exitiosus* is able to tolerate more shade than the beet leafhopper, *Circulifer tenellus*.

Despite the large numbers of leafhoppers in sugar beets at the La Platina Station during March and April of 1966, they were relatively rare on the weeds of the area. A few were found on *Veronica persica* and *Amaranthus* spp., but they were scarce on *Chenopodium album, Convolvulus arvensis,* and other weeds of the area, even when these were growing among beets with relatively high leafhopper populations.

Eggs and nymphs were found on *Amaranthus retroflexus* in beet fields near Linares, but even here the insects were more abundant on sugar beet. No leafhoppers were found on sunflower although a few were found on weeds growing in sunflower fields.

Growth of desert-type vegetation in both Argentina and Chile was at a very low level at the time observations were made on leafhopper populations and most of the annual species had matured and died. Information is needed on spring populations on weeds in desert areas and on the extent of migration of insects to beet fields from weeds as the desert vegetation dries up. Information is needed, particularly on the influence of favorable hosts of *P. exitiosus*, such as *Erodium moschatum* and *E. Cicutarium* in supplying both vectors and virus for infection of sugar beet.

It has been tacitly assumed that *P. exitiosus* migrates from desert areas into beet fields in the spring in much the same way as the beet leafhopper moves into beet fields in the United States. This, however, needs further study. *P. exitiosus* has a relatively long life cycle and the beginning spring populations probably are very low. Moreover, it is not known whether this insect will move long distances. There apparently have been no observations indicating marked movement of leafhoppers into beet fields in the spring. Where observations have been made, which appear to be limited to small plots, the spring populations are low and increase takes place throughout the season on beet where temperature conditions are favorable for increase.

Relationship of the Virus to the Vector

Much additional work needs to be done before complete information regarding the relationship of the virus to the vector is available. Fairly comprehensive tests were made through March to June, 1966, at the La Platina Station to determine the more common relationships of the virus to the vector, but in most

tests infection was so low that conclusive results were not obtained. However, the results do permit certain tentative conclusions and point the way to the proper planning of future tests that will be required for obtaining more extensive information.

Acquisition-Feeding Period Tests were made in which nonviruliferous adult leafhoppers were allowed feeding periods on diseased beet plants ranging from 6 hours to 7 days, after which the leafhoppers were placed in leaf cages (4 leafhoppers per cage), and allowed to feed on seedling plants of sugar beet or *Chenopodium capitatum* for at least 7 days. In these tests, 391 leafhoppers were used.

In a second test, to determine incubation period of the virus in the vector, 35 nonviruliferous leafhoppers were allowed to feed on a diseased beet plant for 24 hours. They were then placed in leaf cages (three per cage) and allowed to feed 24 to 96 hours on plants in seven successive transfers for a period of 18 days.

No infection was obtained in either of these tests. This result was unexpected. A completely satisfactory explanation for the failure of these leafhoppers to acquire and transmit virus is lacking. It seems unlikely that all of these leafhoppers failed to acquire virus from diseased plants. It may be, however, that they acquired virus but failed to transmit because of a long incubation period in the vector. If the incubation period of the virus in the vector is longer than 20 days, transmission would not be expected from these tests.

Transmission Feeding Period To test the effect of duration of feeding period on infection, 10 viruliferous adult leafhoppers, five in each of two leaf cages, were allowed to feed different periods on seedling sugar beet plants. Twenty plants were inoculated for each time period and the same insects were transferred from one series of plants to the next over the entire period of the test, except that leafhoppers that died were replaced by other leafhoppers from a viruliferous colony.

The results (Table 5) show that transmission was produced in a feeding period of 1 hour and indicate that the percentage of infection increased with feeding period up to 8 hours after which there is no indication of increased infection. Considering the fact that 10 viruliferous leafhoppers were used on each seedling beet, the percentage of infection is lower than would be expected with a highly efficient vector. Under similar conditions, *Circulifer tenellus* would be expected to transmit curly top virus to nearly all inoculated plants.

Table 5.—Effect of length of feeding period on transmission of yellow wilt virus to seedling sugar beet plants by *Paratanus exitiosus*.

Feeding period	Plants inoculated and infected[1]	Infection
Hours	Number	Percent
1	1/20	5
2	2/20	10
4	3/20	15
8	6/18	33
17	7/19	37
24	9/20	45
48	7/18	39

[1] The numerator indicates number of plants infected; the denominator the number of plants inoculated.

Tests for Passage of the Virus Through the Egg Stage of the Vector One hundred and nineteen nymphs from eggs laid on diseased beet plants by viruliferous leafhoppers were removed with a brush as they hatched from eggs and caged (1-10 per plant) on 55 plants of sugar beet or *Chenopodium capitatum* for a week or more. None of these plants showed symptoms or yellow wilt. In a second test, 20 newly hatched nymphs were placed on a beet plant in a breeding cage and permitted to mature and produce progeny. The original beet in the breeding cage remained free of symptoms. Numerous transfers of progeny to seedling plants of sugar beet and *Chenopodium capitatum* over a period of 2 months failed to produce infection. While these results do not prove that the yellow wilt virus cannot be transmitted through the egg stage of the vector, they do indicate that if ovarial passage of the virus does occur it takes place through a low percentage of the eggs.

Retention of the Virus by the Vector To obtain information on the period viruliferous leafhoppers are able to retain virus, a test was made in which 10 nymphs and 10 adult leafhoppers from a viruliferous colony were transferred singly on seedling sugar beets at daily intervals. The test was run for 15 days. The mortality of leafhoppers was relatively high. Replacements were made from caged leafhoppers from the same source, also transferred at daily intervals.

The results of this test (Table 6) show that the virus was transmitted by both nymphs and adults. Of the original insects, six failed to transmit over their period of feeding, 13 transmitted to a low percentage of plants and one transmitted to 11 successive plants before it died on the 11th day. These results, along with those obtained with replacements, indicate a very low efficiency in transmission by the average leafhopper. However, the fact

Table 6.—Transmission of yellow wilt virus by individual leafhoppers in daily transfers on sugar beet seedlings.

Leaf-hopper number	Nymph or adult	Results in successive daily transfers[1]														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	N	—	—	—	+	—	—	—	—	—	A	—	+	—	—	—	—	—
2	N	—	—	—	—	—	—	—	—	—	—	A	+	—	D	—	—	—
3	N	+	+	+	+	+	+	+	+	+	+	A	+	DN	—	—	—	—
4	N	—	—	—	—	—	—	—	—	—	—	—	—	—	DA	—	—	—
5	N	—	—	—	A	—	—	+	—	—	—	—	—	DN	—	—	—	—
6	N	—	—	—	—	—	—	—	+	DN	—	—	—	—	—	—	—	—
7	N	—	—	—	+	+	—	A	—	—	—	—	—	—	—	—	—	—
8	N	—	—	—	—	—	—	—	—	—	—	A	—	—	—	—	—	—
9	N	—	—	+	—	—	—	+	—	—	—	—	—	—	—	—	—	—
10	N	—	—	+	—	—	—	+	—	—	—	—	—	—	DN	—	—	—
11	A	—	—	—	—	+	—	—	+	—	—	—	—	—	—	—	—	—
12	A	—	—	—	—	—	—	+	DN	—	—	—	—	—	—	—	—	—
13	A	+	—	—	—	—	DA	—	—	—	DA	—	—	—	—	DA	—	—
14	A	—	—	—	—	—	—	DA	—	—	—	—	—	—	DN	—	+	+
15	A	—	—	—	+	—	DA	—	—	DN	—	—	—	—	—	+	—	—
16	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17	A	+	—	—	—	—	—	—	—	—	—	—	—	—	DN	—	—	—
18	A	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19	A	+	—	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—
20	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	DA	—

[1] A indicates nymph became an adult; DN indicates original leafhopper died and was replaced with a nymph; DA indicates original leafhopper died and was replaced with an adult. Plus (+) and minus (—) indicate transmission and no transmission, respectively.

that one leafhopper transmitted to all of the 11 plants on which it fed over a period of 11 days, suggests that there may be a wide range of efficiency among individuals of a colony. It might be possible, therefore, by selection and breeding, to develop a line of leafhoppers with relatively high transmissive ability. Such a line of vectors would be valuable in a number of ways in yellow wilt studies, and would add greatly to the ease of making inoculations in selection for resistance to the disease.

Damage Caused by Yellow Wilt

General

The damage produced by yellow wilt depends in part on the phase of the disease prevalent in the beet field. In the wilt phase, which seems to be more prevalent under conditions of high temperatures and low humidities leading to high transpiration rates, the loss may be total for all infected plants. Diseased plants wilt and the tops die within a few days. The roots shrivel and rot and become a total loss. Under these conditions the loss is equivalent to the percentage of infected plants that show symptoms. Some fields in the Rio Negro Valley of Argentina were reported as total losses in the years 1937-38 and 1938-39 and the yield in the entire area was very low. Averages were 5.6 and 3.0 metric tons per hectare, respectively, in these two years as compared to a yield of 15.0 metric tons per hectare in 1935-36. Even in the better years the disease was reported to have caused considerable damage. One 2-hectare experimental plot near Conesa, Argentina, was observed through the month of January, 1941, during which time 95% of the plants died or became badly diseased.

In April, 1966, experimental plots of beets were observed in Argentina at San Rafael, La Consulta Experiment Station, and at Mendoza. Yellow wilt infection ranged from rather low at San Rafael to more than 50% in some tests near Mendoza. In tests near Mendoza most of the infected plants were dead and the roots were shriveled and rotted.

Experimental

The effects of natural infection on growth and sucrose content were determined in 1965-66 in a test at the La Platina Experiment Station near Santiago, Chile. Data were taken from seven U. S. varieties (US H2, US H6, US H7, US H8, US 75, US 33, US 41) and KWS E, the variety grown most widely in Chile. These varieties were entries in a larger trial to screen material for yellow wilt resistance. The plots, two rows x 11 m, were planted in two replications on November 18, 1965. Leafhoppers

were present in low numbers on January 1, 1966 and were numerous by February 15. They continued to increase throughout the season and were present in large numbers at harvest on April 20.

Infection became evident the early part of February and increased to 30% by February 18, to 60% on February 28, and to 88% at harvest. Most of the infected plants developed the yellows phase of the disease and continued to live throughout the season, but development was markedly retarded and there was little increase in weight of either tops or roots after the appearance of first symptoms. Relative time of appearance of symptoms could be estimated on the basis of the number of more or less normal leaves on the diseased plants.

At harvest time the plants in each plot of the eight varieties were divided into 5 classes, based on conditions of the tops. Class 1: healthy, no leaves showed symptoms. Class 2: late infected, young leaves showed symptoms, older leaves showed no symptoms. Classes 3, 4 and 5: early infected, all leaves with symptoms, but representing increasing severity of disease as judged by top size. Tops and roots of the plants in each class were counted and weighed and a sample of roots taken for sugar analysis from all classes except 2 (late infected). Visually, late infected plants appeared as vigorous as healthy plants. As Table 7 indicates, the tops of these plants were somewhat smaller than tops of healthy plants but they showed no reduction in root weight.

Table 7.—Reduction in top and root yield and sucrose percent by yellow wilt virus in tests at La Platina, Chile.

Disease rating[1]	Average weight per plant		Sucrose content	Sucrose, total per plant[2]	Sucrose reduction
	Top	Root			
	Grams	Grams	Percent	Grams	Percent
1 (Healthy)	720	950	14.1	134	—
2 (Late infected)	550	970	—	—	—
3	400	640	13.8	88	34
4	230	370	12.5	46	66
5	110	140	10.8	15	89
LSD, 5%	100	120	0.6		

[1] The ratings 1 to 5, respectively, indicate healthy appearing plants (class 1), plants recently infected (class 2) and plants infected for a longer period and showing progressively more severe symptoms (classes 3 to 5, inclusive).

[2] Calculated from the average root weight and percent sucrose.

The disease affected all varieties similarly. Table 7 shows the effect of the virus, averaged over all varieties. Reduction in weight of both roots and tops of the early infected plants (classes 3, 4 and 5) appears to correlate well with visual rating of tops. Sucrose content was reduced as much as four percentage points

and appears also to correlate with visual rating of tops. Reduction in sucrose percent is in contrast with results with the curly top disease of sugar beet where the percent sucrose appears to remain about the same regardless of the effect of the disease on root size.

The correlation between reduction in root size with reduction in top size indicates that resistance to the yellowing phase of the yellow wilt disease may be judged by the appearance of the tops alone and that selections for resistance probably could be made on the basis of the appearance of the tops. In this instance, however, where disease was produced by natural infection resulting from a gradual increase in vector population, it is not known whether the differences between plants in classes 3, 4 and 5 represent differences in time of infection or inherent difference in resistance. It appears most likely that differences were largely due to differences in time of infection.

Control Measures

The control of yellow wilt thus far has depended on the selection of areas for sugar beet production in which the vector and virus are absent or not present in sufficient quantities to cause serious damage. This method of control limits the possibilities for production of sugar beets in Argentina and Chile to areas with considerable precipitation and eliminates some of the irrigated areas that otherwise are highly suitable for sugar beet production. In these latter areas, it seems probable that successful sugar beet production will depend on the development of varieties resistant to yellow wilt or on chemical control of the vector, or both.

Production of Resistant Varieties

The production of varieties resistant to yellow wilt probably will be difficult and will require considerable time. As yet, there is no evidence that any commercial variety of sugar beet has appreciable resistance. In 1938-39, 20 European varieties and two varieties from the United States were tested for relative susceptibility in variety test plots near Conesa, Argentina. The disease was very severe and large percentages of plants of all varieties were infected. There was no evidence, however, that any one of these varieties was superior to any other in resistance. The test, repeated in 1939-40 with 28 European varieties and three varieties from the United States, gave similar results (2).

Bravo (3) reported differences in resistance among varieties of sugar beet tested in Chile in 1962, but the test plots were small and the margin of error seems too large to justify definite conclusions.

As previously mentioned, varieties were screened for resistance in a test at La Platina in 1965. Thirty-five U. S. varieties and KWS E were planted in replicated plots and subjected to natural infection. Infection increased steadily through the season from the middle of January 1966 and reached 88% at harvest, April 20. As shown in Table 8, there were no readily detectable differences among the varieties tested. If a variety possessed a degree of resistance it should have been reflected as a significantly higher percentage of early infected plants with mild (class 3) to moderate (class 4) symptoms (Table 8, column 4). In this respect, there were no significant differences among the varieties. The "disease index" of Table 8 is another criterion of relative resistance. To obtain this index, disease classes of early infected plants (all leaves showing symptoms) were given ratings of 1 (mild), 2 (moderate) and 3 (severe). These disease ratings (DR) were weighted by the number of roots in each category to calculate a disease index (DI) for each plot: DI = [1 (no. mild symptoms) + 2 (no. moderate) + 3 (no. severe)]/total no. infected early. The lower the disease index, the more relatively tolerant the variety. There were no significant differences in the disease index. The two varieties with lowest disease indices and the highest percentage of early infected plants with mild to moderate symptoms were FC (502 × 503) MS × 4n pool and 549H3 × NB7.

A factor that may add to the difficulty of producing varieties resistant to yellow wilt is the expression of symptoms in two phases, namely, yellowing, and wilting. As nearly as could be judged by observation of plants in the plots at La Platina in 1966, there may be some resistance to the yellowing phase of the disease in some varieties. Plants apparently infected when small, as indicated by the fact that all remaining leaves showed symptoms, had an appreciable range in top and root size. The correlation between top and root weight for such plants was 0.91. The regression equation for predicting root weight from top weight was $Y = -0.0199 + 1.614X$, where Y = root weight (Kg/plant) and X = top weight (Kg/plant). It seems reasonable to expect that exposure to early, uniform inoculation and selection and propagation of the least damaged plants under these conditions might lead to resistance to the yellowing phase. It is difficult to predict, however, what would happen to such resistant selections if they were subjected to conditions for production of the wilt phase of the disease.

Perhaps selection for resistance to yellow wilt could best be made under two conditions: (a) under conditions that produce the yellowing stage of the disease, and (b) under conditions that

Table 8.—Effect of natural infection by the yellow wilt virus on varieties at the La Platina Station (Instituto de Investigaciones Agropecuarias), Santiago, Chile, 1965-66. The data were taken at harvest on April 20 and are means of two replications.

Variety	Percent yellow wilt at harvest				Roots	
	Total plants infected	Plants infected early[1]	Moderate to Mild Symptom[2]	Disease index[3]	Number per plot	Metric tons/ hectare
US215 × 216	86	66	67	1.9	102	46.1
US216 × 225	95	84	73	1.9	92	39.4
US216; I-16-0	92	76	75	1.9	104	43.3
US216MS × 226	88	67	66	2.0	110	48.8
SL126MS × SP5460-0	90	72	75	1.9	102	54.8
SL (126 × 128) MS × SP5460-0	95	82	76	1.9	98	52.5
SL126MS × SP5822-0	89	74	73	1.9	100	47.7
SL(126 × 128)MS × SP5822-0	91	71	71	1.9	107	47.2
SL(126 × 128)MS × US40H4n; triploid	89	64	72	1.9	105	48.0
SP5822-0	91	67	78	1.8	105	51.4
SL(129 × 133)MS × SP5822-0	88	66	55	2.2	108	53.2
CT5MS × SP5822-0	91	71	69	2.0	102	50.0
SL(129 × 133)MS × SP6322-0	81	64	72	2.0	119	50.3
SP6051-0	92	73	60	2.1	98	46.8
FC(502/2 × 503)MS × S-62-16; triploid	88	70	81	1.8	102	54.2
FC(502 × 503)MS × SP59818-0	89	80	70	2.0	109	43.9
FC(502 × 503)MS × McF663	92	76	66	2.1	120	46.6
FC(502 × 503)MS × 4n pool, triploid	90	71	84	1.7	106	46.2
F61-5621HO × 2648)MS × SP63325-02	84	54	66	2.0	100	50.2
USH2	90	79	48	2.3	108	60.4
USH6	92	74	58	2.1	87	47.5
USH7	87	74	56	2.2	111	59.5
USH8	90	70	71	2.0	100	51.0
US75	86	70	64	2.1	116	51.4
SLC 129mm rr	68	43	56	2.2	93	42.8
CT7MM	91	81	61	2.1	112	36.0
CT9 × (US 35aa × KWS E)	90	65	78	1.9	94	54.2
Male-sterile multigerm	86	67	68	1.9	108	50.0
US22/3 × US35/2	90	78	70	2.0	110	48.6
US33	90	74	66	1.9	110	51.0
US41	92	70	57	2.2	103	42.6
549H3 × NB7	87	67	83	1.7	100	58.8
546-36H1 × 663	78	49	65	2.0	110	68.0
569H1 × 3425	85	58	71	1.9	131	59.7
US56[4]	83	52	76	1.8	56	33.8
KWS E	86	60	70	2.0	108	65.5
Average, all varieties	88	69	69	2.0	104	50.0
Calculated F value[5]	1.84	1.66	1.40	1.58	1.33	1.78
LSD, 5%	NS	NS	NS	NS	NS	NS
Coefficient of variation (%)	5.86	14.6	14.3	8.20	13.8	15.4

[1] "Infected early" means that all leaves of such plants showed virus symptoms at harvest.

[2] [(Number of plants infected early with mild to moderate symptoms)(100)]/no. plants infected early.

[3] Considering only plants infected early: [1 (No. with mild symptoms) + 2 (No. with moderate symptoms) + 3 (No. with severe symptoms)]/total plants infected early.

[4] Seed germinated poorly.

[5] F values required for significance, 5% and 1% levels respectively: 1.88, 2.45.

produce the wilting stage of the disease. In any selection program it will be necessary for maximum results to produce a very high percentage of infection early in the development of the planting in which selections will be made.

If lines resistant to the yellowing phase are developed, it will still be necessary to test them under conditions that favor the development of the wilt stage of the disease in order to determine their value in commercial beet production.

The feasibility of selection for resistance under conditions for production of the wilting phase of the disease remains to be determined. It is entirely possible that there are no beets that will survive an attack of yellow wilt under such conditions. In all fields in which observations have been made, however, at least a few plants have remained free of symptoms. Selection and propagation of such plants in Argentina have not resulted in resistant progeny (2). The continuation of such a program would seem to be desirable, however, especially where plants can be subjected to high concentrations of inoculum. Under such conditions surviving plants, if any, might prove to have a high degree of resistance to the effects of the virus or a high degree of resistance to infection. If no such plants are found it may be necessary to increase resistance through selection of plants that have some resistance to the yellowing phase of the disease, with the hope that such resistance could eventually lead to resistance to the wilt phase. Such a program is likely to require a great amount of time.

Chemical Control

Tests for control of yellow wilt by use of insecticides were made by Tolosa M. (7) at the Agricultural Experimental Station of the University of Chile at Hacienda Rinconada near Santiago, Chile, in 1961-62. Plantings were made August 22, September 22, October 22, and November 25. Seven insecticides—DDT, Diazinon, Malathion, Metasystox, Sayfos 70, Sayfos 80, and Sevin —were used. Treatment was started in plots of the first and second planting dates as soon as leafhoppers were found, and in plots of the third and fourth planting dates when yellow wilt symptoms began to appear. Treatments were made in plots of the first and second planting dates on November 24, December 20, January 19, and February 18; and in plots of the third and fourth dates of planting on December 16, January 16, February 13, March 12, and April 5, except that plots of the fourth date of planting did not receive the December application.

Statistically significant increases in yield were obtained only in plots of the first date of planting. Best results were obtained

with DDT which gave an increase of about 25% in tonnage. Sucrose content of roots was 15.9% in treated plots and 13.4% in check plots. Lesser increases in yield were obtained with Diazinon, Malathion, Sevin and Metasystox.

Workers in the Mendoza area of Argentina obtained encouraging results in the control of yellow wilt in 1963-64, by the application of insecticides for control of the vector[4].

To obtain additional information on the possibilities for control of the disease by insecticides, an experiment was started at the La Platina Station in 1965. A planting with KWS E was made November 12 and 13. Replicated plots, five rows wide and 20 meters long, were treated with DDT, or Metasystox sprays or with Thimet granules at two-week intervals from shortly after thinning to one month before harvest. The experimental planting was between, but adjacent to, a block of overwintered diseased beets and the previously discussed variety trial which was not treated.

Yellow wilt spread in the variety test and infection reached 88% by harvest. Despite the presence of virus in both overwintered beets and the variety test, and an abundance of vectors in the variety test, little infection occurred in the area of the chemical treatment. At harvest there was only about 10% infection in the treated area. Control was almost as effective in the nontreated check plots as in the treated plots, indicating that the effects of the insecticides extended into the nontreated plots.

The results indicate a high degree of sensitivity of *Paratanus exitiosus* to the insecticides used. They suggest that leafhoppers within a treated area may be readily controlled by the insecticides tested. This evidence, together with the evidence that *Paratanus exitiosus* may not migrate in large numbers into beet fields from adjacent areas, lends further encouragement to the concept that it may be possible to obtain a high degree of control of yellow wilt by means of insecticides.

Summary

The yellow wilt disease of sugar beet, first described as a virus disease in the Rio Negro Valley of Argentina from studies made in 1941, is now known to be present over considerable areas of central Argentina and Chile. It is the most destructive disease known to sugar beet in the areas where it occurs, and it holds potential for extensive destruction of sugar beets in any area of low rainfall in the world where sugar beets are grown, if the causal virus should be introduced along with its known vector.

[4] Oral communications with Ing. Agrónomo Humberto Galmarini, Instituto Nacional de Tecnologia Agropecuaria, La Consulta (Mendoza), Argentina.

There are two distinct types of symptom expression. Under conditions favorable for rapid plant growth, infected plants are yellow and dwarfed and often produce strap-like leaves. Growth of axillary buds may be stimulated which may result in a rosetted appearance in later stages of disease development. Under conditions of high temperature and low humidity, infected plants may wilt and die within a few days without showing other characteristic top symptoms.

The causal virus has been transmitted by graft and by two species of *Cuscuta*, but not by juice inoculation. Under natural conditions it is transmitted by a leafhopper, *Paratanus exitiosus*.

In addition to sugar beet, yellow wilt occurs in the field on table beet, fodder beet, and Swiss chard. It has been found occurring naturally on *Erodium cicutarium* and *E. moschatum*. It has been transmitted in the greenhouse to:

Amaranthus retroflexus (redroot amaranth), *Beta vulgaris* (sugar beet), *Chenopodium capitatum* (strawberry-blite), *C. murale* (nettleleaf goosefoot), *Claytonia perfoliata* (miner's lettuce), *Datura stramonium* (jimson weed), *Erodium cicutarium* (red-stem filaree), *E. moschatum* (white-stem filaree), *Hyoscyamus niger* (black henbane), *Lycopersicon esculentum* (tomato), *Nicotiana bigelovii, N. clevelandii, Spinacea oleracea* (spinach), *Stellaria media* (chickweed), and *Tetragonia expansa* (New Zealand spinach).

The known vector, *Paratanus exitiosus*, is a leafhopper slightly larger than the beet leafhopper, *Circulifer tenellus*, which transmits curly top virus. It appears to be well distributed over the area where it occurs. It requires 55 to 65 days to complete a generation under greenhouse conditions. It has a wide potential host range; sugar beet, filaree, spinach, and horsebean, appear to be excellent hosts. It probably will multiply readily on a number of species of Chenopodiaceae, including Russian thistle, and several species of *Atriplex* widely distributed in the United States.

The relationship of the virus to its vector is incompletely known, but preliminary tests indicated that the virus is retained for the life of the vector. The virus may have a relatively long incubation period in the vector, but it apparently does not pass through the egg stage. The leafhopper can transmit virus in a feeding period of 1 hour but infection increases with increase in period of feeding. As compared with the beet leafhopper, it is an inefficient vector.

Field tests near Santiago, Chile, in 1965-66 indicated that losses due to the yellowing phase of the disease may range up

to 90%, depending on time of infection. The wilting phase may cause losses equal to the percentage of infection.

No variety of sugar beet is known to have appreciable resistance to the disease. Control measures, thus far, have consisted of avoiding areas where the disease is likely to be severe. There is some evidence that insecticides, under some conditions, may be effective in control of the vector.

Acknowledgments

The authors thank Industria Azucarera Nacional S.A., the Instituto de Investigaciones Agropecuarias and the University of Chile for providing the greenhouse and field facilities for this research and, particularly, Ing. Agrónomo Mario Vallejo, Chief of the Agricultural Technical Department, IANSA, for his help in facilitating this work.

Thanks also to Ing. Quimico José A. Masera and the staff of the Comisión Promotora Azucarera, Ministerio de Economia, Gobierno de Mendoza, Argentina for assistance in surveying yellow wilt and curly top problems in Argentina and to Dr. Luciano Campos of the University of Chile and Ing. Agrónomo José Plaza de los Reyes of IANSA for help in rearing colonies of *Paratanus exitiosus*..

Literature Cited

(1) BEAMER, R. H. 1943. A new Atanus from Argentina, South America (Homoptera cicadellidae). Wash. Ent. Soc. Proc. 45: 178-179.

(2) BENNETT, C. W. and CARLOS MUNCK. 1946. Yellow wilt of sugar beet in Argentina. J. Agr. Res. 73: 45-64.

(3) BRAVO LATORRE, OSCAR. 1963. Comportamento de 30 variedades de remolacha a la marchitez virosa producida por *Chlorogenus patagoniensis*. Thesis presented in partial requirement for the degree of Ingeniero Agrónomo, University of Chile. (Unpublished).

(4) EHRENFELD K., ROBERTO. 1962. Investigaciones virologicas en remolacha. Thesis presented as partial requirement for the degree of Ingeniero Agrónomo, University of Chile. (Unpublished).

(5) HENDERSON, C. F. 1928. Exploration in the Argentine Republic, for parasites of the beet leafhopper, *Eutettix tenellus* (Baker). J. Econ. Ent. 21: 863-871.

(6) LINNAVUORI, G. 1959. Revision of the neotropical Deltocephalinae and some related subfamilies (Homoptera.). Ann. Zool. Soc. "Vanomo" 20: 1-370.

(7) TOLOSA M., JAIME. 1963. Control quimico del langostino (*Paratanus exitiosus* (Beamer)) vector de la "marchitez virosa" en betarraga azucarera (*Beta vulgaris* L.). Thesis presented in partial requirement for the degree of Ingeniero Agrónomo, University of Chile (Unpublished).

(8) VALLEJO, MARIO. 1964. Investigation on "yellow wilt" of sugar beet and the evaluation of breeding material for resistance to the virus. Ann. Rept. of Res. Conducted under Grant Authorized by U. S. Public Law 480. 16 pp. (Unpublished).

(9) VALLEJO V., MARIO. 1965. Investigation of "yellow wilt" of sugar beet and the evaluation of breeding material for resistance to the virus. Biennial Rept. of Res. Conducted under Grant Authorized by U. S. Public Law 480, Jan. 1 to June 30, 1965. (Unpublished).