

**ILLINOIS**  
**Natural History Survey**  
**BULLETIN**

**An Urban Epiphytotic  
Of Phloem Necrosis and  
Dutch Elm Disease, 1944-1972**

**Cedric Carter**  
**Heile Rogers Carter**

NATURAL HISTORY SURVEY

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**Medric Carter**  
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**STATE OF ILLINOIS**  
**DEPARTMENT OF REGISTRATION AND EDUCATION**  
**NATURAL HISTORY SURVEY DIVISION**  
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Frontispiece.—These before and after pictures along the Broadwalk on the University of Illinois campus illustrate vividly how a cathedral-like archway of stately American elms can be destroyed quickly and completely by phloem necrosis and Dutch elm disease. The upper photograph was taken in September 1954. The lower photograph was taken in September 1966, several years after the university had begun replacing the elms with other species. (Upper photo by W. E. Clark; lower photo by W. D. Zehr)



# An Urban Epiphytotic of Phloem Necrosis and Dutch Elm Disease, 1944–1972

J. Cedric Carter  
Lucile Rogers Carter

THE AMERICAN ELM was used more extensively than any other species as a shade tree in Illinois prior to 1940. It was especially valued for its rapid growth, majestic size, vase shape, and extensive shade. It was used for streets, boulevards, and park drives, as well as in lawns. In many cities throughout the state it represented half or more of the shade trees lining the streets. In some cities it was estimated that three-fourths of the shade trees were American elms. Because of the loss to diseases of millions of elms, especially American elms, since 1940, most cities and homeowners now plant other trees. The elm problem has made many people aware of the importance of using diversified plantings to avoid such a catastrophe in the future.

Extensive dying of elms in central Illinois, especially in Bloomington, Normal, and Champaign, occurred as early as 1883 (Forbes 1885:112; 1912:3). This dying of elms subsided within a few years. Although the cause of the elm deaths was not determined, the symptoms reported are not typical of any current vascular wilt disease.

In 1907 elms were reported dying in southern Illinois in and around Fairfield in Wayne County. By 1912 numerous elms were dying in 14 towns (Cairo, Carbondale, Centralia, Clayton, Du Quoin, Edwardsville, Fairfield, Galatia, McLeansboro, Mt. Vernon, Quincy, Robinson, Sumner, and Vandalia) in 13 counties in southern and western Illinois (Forbes 1912:5). Careful examination of affected trees revealed that although the small fibrous roots were dead, some of the main roots were alive, as were some of the leaves. This early dying of elms was generally

referred to as "elm blight" and attributed to various conditions and agencies, including drought, exhaustion of soil nutrients, insect attack (borers and bark beetles), and diseases of unknown causes (Forbes 1912:7–10).

Following 1912 no reports of extensive dying of elms appeared until 1930, when many elms were killed in and near several large and small cities, notably Hillsboro in south-central Illinois, Danville in east-central Illinois, Peoria in north-central Illinois, Quincy in west-central Illinois, and Cairo at the southern tip of the state (Carter 1945:23). By 1940 (Carter 1954) elms were dying throughout the southern half of the state and as far north as Danville on the east and Quincy on the west. Other towns on the northern border of this area included Charleston, Shelbyville, Taylorville, and Pittsfield. The greatest number of affected trees were in a broad belt extending diagonally southwestward from Danville and Paris on the east to Alton and Belleville on the west. This area is north of the southern part of the state where heavy losses of elms occurred earlier. This dying of elms continued to spread northward to Urbana in 1944, to Mattoon, Springfield, and Lincoln in 1945, and to Decatur, Bloomington, and the area around Burlington, Iowa, in 1948. General and widespread dying of elms became stabilized by 1948 with the northern boundary of the affected area represented by a line extending from Danville on the east through Champaign-Urbana, Bloomington, and Peoria to the area around Burlington, Iowa, on the west. North of this area dying elms were found in only six cities — Melvin

and Dwight in 1945, Rockford in 1946, Chebanse in 1950, and Chenoa and Onarga in 1953.

Following the 1938 report that a disease of a virus nature was killing elms in Ohio (Swingle 1938), it was soon determined that the widespread dying of elms in the Ohio Valley region of the Midwest was caused by the same disease. It was determined to be a virus disease called phloem necrosis (Swingle 1940 and 1942). However, recent work by Wilson et al. (1972) indicates that elm phloem necrosis may be caused by a mycoplasma-like organism (MLO).

The symptoms exhibited by dying elms in Illinois as early as 1912 were typical of those described later for phloem necrosis. It appears that this disease was the major cause of elms dying in southern Illinois from 1907 to 1950.

Dutch elm disease, caused by *Ceratocystis ulmi* (Buism.) C. Moreau, was discovered in one American elm in Coles County (east-central Illinois) in 1950, and the disease spread rapidly, especially in the area where elm phloem necrosis was killing thousands of elms annually. By 1969 it had spread into all 102 counties of the state. At present each disease kills many elms annually, phloem necrosis in the southern two-thirds of the state and Dutch elm disease throughout the state.

The first symptom of phloem necrosis is the dying of fibrous roots. This symptom is followed by foliage symptoms, which appear as drooping leaf blades and upward curling leaf margins. Next the leaves turn yellow, brown, or both, and drop from the tree. These symptoms may occur over one or more growing seasons. On some trees the foliage wilts rapidly within a few weeks and turns brown, but many leaves remain attached to the branches. Occasionally a tree may have one or a few large branches dying simultaneously over a period of 1 or more years.

The infection of individual branches by the Dutch elm disease fungus re-

sults in wilting and dying foliage on the affected branches. Frequently, the early symptom of Dutch elm disease is wilting foliage on one or a few branches. Wilt of the entire tree occurs after the fungus becomes systemic in the tree. The yellowing of leaves over the entire crown is uncommon in Dutch elm disease but common in phloem necrosis.

The present study was initiated, following the appearance of phloem necrosis in Urbana in 1944, to obtain data on the number of elms affected annually by the disease and to study the pattern of spread in a municipal area where no city-wide control program was practiced. With the appearance of Dutch elm disease in Urbana in 1951, the study was expanded to include both diseases and the relationship of the two diseases in a municipal area.

## ACKNOWLEDGMENTS

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## LITERATURE REVIEW

Field-grown elms do not show symptoms of phloem necrosis for 1 or more years following the introduction of the MLO (Baker 1949:729, 730; Campana 1958). Elms affected by this disease usually die during the growing season in which symptoms first appear. However, some elms may show symptoms for two or sometimes three growing seasons before dying (Campana 1958; Swingle 1938:757). Phloem necrosis affects only the American elm (*Ulmus americana* L.) and its cultivars and the winged elm (*U. alata* Michx.). The phloem necrosis MLO is carried by the elm leafhopper (*Scaphoideus luteolus* Van D.). The MLO is introduced into the leaves of healthy elms by the feeding activity of elm leafhoppers that have previously fed on leaves of phloem necrosis-affected elms.

Elms affected by Dutch elm disease may die during the growing season when symptoms first appear, or they may die during the following growing season. Occasionally an affected elm may not die until the third growing season (Banfield, Rex, & May 1947). Dutch elm disease affects all elm species, but the Asiatic species are relatively resistant (Bretz, Swingle, & Parker 1945). The American elm appears to be more susceptible than the other native and European species (Neely & Carter 1965).

Published data on the loss of elms in municipal areas where both diseases occur are limited. However, data are available on losses caused by each disease in areas where only one was present (Campana & Carter 1955 and 1957; Carter 1954, 1955, and 1961; Neely, Carter, & Campana 1960; Neely 1967).

In municipal plantings of elms, losses resulting from phloem necrosis may increase from a few scattered trees when the disease is first discovered to several hundred trees annually within 3 years. In three municipalities in central Illinois the number of phloem

necrosis-affected elms increased from 9 in 1945 to 370 in 1948 in Lincoln, from 5 in 1945 to 417 in 1948 in Mattoon (Carter 1950:50), and from 6 in 1948 to 154 in 1951 in Bloomington.<sup>1</sup> In Mt. Pulaski, which had approximately 600 elms in 1942 when phloem necrosis was first found there, all but 19 elms were killed by the disease by 1948 (J. C. Carter, unpublished data).

Phloem necrosis also kills elms in rural areas. In a survey made in southern Illinois in 1945, the numbers of elms recorded as dying from phloem necrosis were 1,644 in rural areas and 1,655 in municipal areas (Carter 1954).

In municipal plantings of elms, Dutch elm disease losses may increase from a few scattered trees when the disease is first discovered to hundreds of trees each year in a few years. In five municipalities in northern Illinois where Dutch elm disease was discovered in 1955 and where phloem necrosis was not present, the total numbers of diseased elms from 1955 through 1961 were over 4,400 in Aurora, 1,600 in Elgin, 2,500 in Joliet, 1,400 in Waukegan, and 1,000 in Zion. The percentages of the original elm populations that became diseased in these five cities during this period were 48, 23, 33, 11, and 27, respectively (Neely 1967: 513). In Bloomington in north-central Illinois, Dutch elm disease was first found affecting 10 elms in 1954 following a 6-year period in which 932 elms were affected by phloem necrosis. The number of elms affected annually by Dutch elm disease increased to 242 in 1955 and to 507 in 1956 (Campana & Carter 1957: 636).

In areas where both diseases are present, the incidence of phloem necrosis results in an increase in the occurrence of Dutch elm disease (Campana & Carter 1955). The native elm bark beetle (*Hylurgopinus rufipes* Eichh.) and the smaller European elm

<sup>1</sup> The data on the loss of elms in Bloomington were obtained by annual surveys made by the senior author.

bark beetle (*Scolytus multistriatus* Marsh.), vectors of the Dutch elm disease fungus, colonize and overwinter in the bark of weakened, dying, and recently killed elms, including those affected by phloem necrosis.

The incidence of Dutch elm disease does not increase the occurrence of phloem necrosis (Campana 1958). Elms killed by either disease and left standing are not colonized by the elm leafhopper (*S. luteolus* Van D.), vector of the phloem necrosis MLO. This insect overwinters in the egg stage. The eggs are embedded in the soft cork parenchyma of elm bark (Baker 1949: 731).

Dutch elm disease may not only obscure the presence of phloem necrosis, but it may kill phloem necrosis-affected trees before external symptoms of phloem necrosis become apparent (Campana & Carter 1957; Campana 1958). The rate of increase of Dutch elm disease exceeds that of phloem necrosis in areas where Dutch elm disease appears after phloem necrosis has been present for several years (Campana & Carter 1957:639; Carter 1955:36-37; Neely, Carter, & Campana 1960:167, 169).

Phloem necrosis-affected elms colonized by smaller European elm bark beetles infested with the Dutch elm disease fungus will harbor that fungus. Of 40 such trees examined in Urbana in 1952, 8 contained the Dutch elm disease fungus (Campana 1954:358).<sup>2</sup> Populations of the smaller European elm bark beetle increase rapidly in areas where dying and recently killed elms are present. This situation was common in the 1950's in the southern two-thirds of Illinois where thousands of elms killed annually by phloem necrosis were not removed immediately upon discovery of the disease (Campana 1954).

When symptoms of both diseases occur in one elm, infection by the phloem necrosis MLO most likely occurs first, since the MLO is in the tree 1 year or more before symptoms of phloem necrosis become apparent (Baker 1948 and 1949:729, 730; Campana 1958; Swingle 1938). Therefore, elms showing early symptoms of phloem necrosis may show symptoms of Dutch elm disease later in the same year or in the following year before they die. Elms infected by the phloem necrosis MLO and the Dutch elm disease fungus in the same year may show symptoms of Dutch elm disease in that year, but not symptoms of phloem necrosis.

Some of the data presented in this bulletin on the loss of elms from phloem necrosis and Dutch elm disease in Champaign and Urbana have been reported previously (Campana & Carter 1955 and 1957; Carter 1955; Neely, Carter, & Campana 1960).

## MATERIALS AND METHODS

The twin cities of Champaign and Urbana represent a contiguous municipal area with a common boundary. This area is approximately 5 miles [8 km] east and west and 2.5 miles [4 km] north and south. It is traversed by approximately 200 miles [320 km] of streets, mostly lined with trees on each side and with additional trees in lawns.

In 1950 all elms and all other species of trees were counted in 75 city blocks to obtain an estimate of the entire tree population as well as the elm population. To obtain the estimate, the entire tree population was divided into 25 areas. The areas were selected so that each area included elms of a given size and age. The sizes of trees counted varied from approximately 4 to 20 inches [100-500 mm] in trunk diameter and 20-75 feet [6-23 m] in height. Most of the larger elms were present in the older residential areas.

All trees were counted in each of three blocks selected at random in each

<sup>2</sup> Data originally gathered by E. B. Himelick, Illinois Natural History Survey, and published by Campana.

of the 25 areas. From the data obtained (Table 1) it was estimated that there were 12,195 elms in the municipal study area. The data also showed that the tree population was composed of 51 percent elms and 49 percent other species. An estimated 2,000 elms in Crystal Lake Park in the north part of Urbana were later included in the total elm population, bringing to 14,195 the estimated number of elms in the

Table 1.—Estimated tree population in Champaign-Urbana, Illinois, in 1950.

City	Elms		Other Species	
	Num- ber	Per- cent	Num- ber	Per- cent
Urbana	4,235	51.8	3,946	48.2
Champaign	7,960	50.6	7,775	49.4
Total or percent	12,195	51.0	11,721	49.0

twin-city area. The actual number of elms recorded during this 29-year study was 14,103. Of these elms, 66 percent were on public property and 34 percent on private property. The distance between elms along many streets was 30 feet [9 m] or less. This close spacing was common in blocks and along streets planted almost exclusively to elms. Some lots with frontages of about 50 feet [15 m] in residential areas had two elms on the parkway and one or more elms on the front lawn.

The elms under observation included all American and European species of elms that could be observed from the street on public and private property within the confines of Champaign and Urbana. In addition to the American elm and its cultivar, the Moline elm, there were 25 slippery elms and 9



Fig. 1.—Phloem necrosis symptoms. The tree on the left shows typical symptoms of phloem necrosis in contrast to the healthy tree on the right. Phloem necrosis is indicated by the cupping or rolling and yellowing of foliage over the entire tree crown. (Photo by J. C. Carter)

English elms. Asiatic species were not included, as they are immune to phloem necrosis and resistant to Dutch elm disease. The elms on the University of Illinois campus were sprayed for 5

years to control phloem necrosis, and therefore they were not included in this study.

Elms removed from the study area but not affected by phloem necrosis or

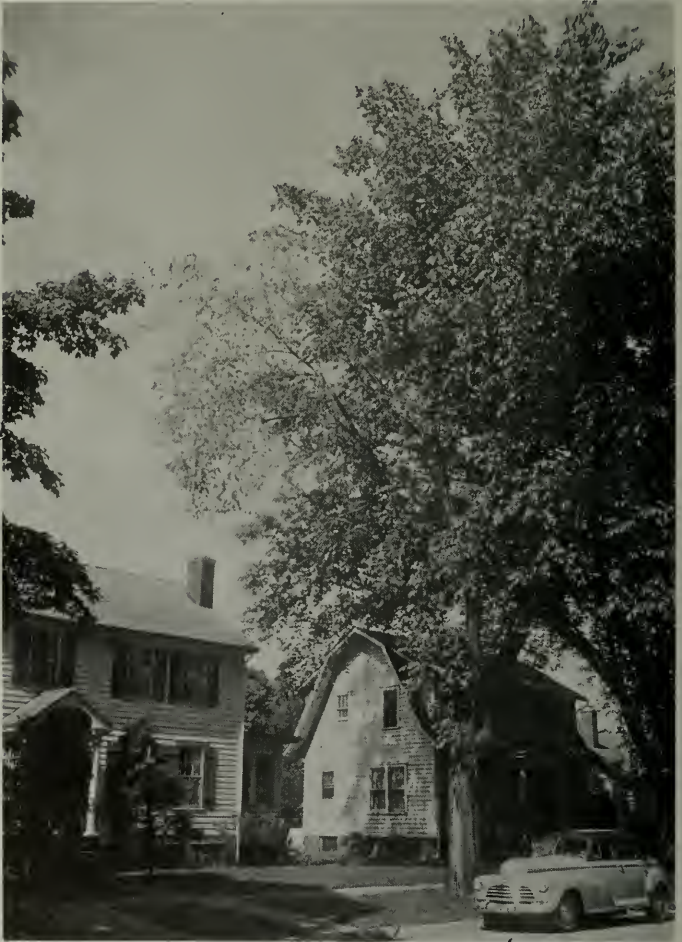


Fig. 2.—Dutch elm disease symptoms. Dutch elm disease frequently appears as wilting and browning of foliage on one or a few branches. This tree has foliage wilting on the left major branch. (Photo by J. C. Carter)



CHAMPAIGN-URBANA  
AND VICINITY

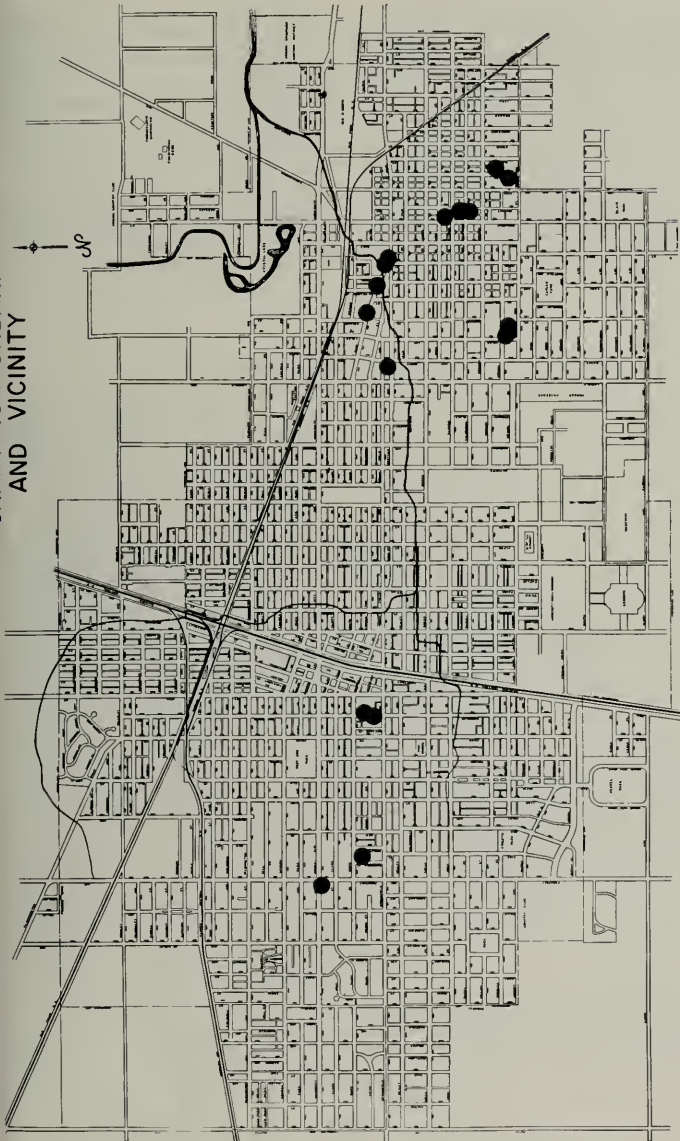


Fig. 3.—Locations of 16 elms affected by phloem necrosis from 1944 through 1948 in Champaign-Urbana, Illinois.

Dutch elm disease, except seven elms removed in 1967 because of ice damage, were not included in the total number of trees recorded in this study. However, elms that became large enough to be seen from the street during the 29-year period were included.

The appearance and spread of each disease were recorded, starting with the first two trees attacked by phloem necrosis in 1944. Dutch elm disease did not appear until 1951.

Observations were made at irregular intervals during the growing season from 1944 through 1950 to determine the incidence and pattern of spread of phloem necrosis. Diseased trees were located by frequent scoutings. As many as 8-14 scoutings were made in a growing season.

After 1950, the authors made two surveys annually through 1972, one in June and one in September. However, in some years the first survey was not

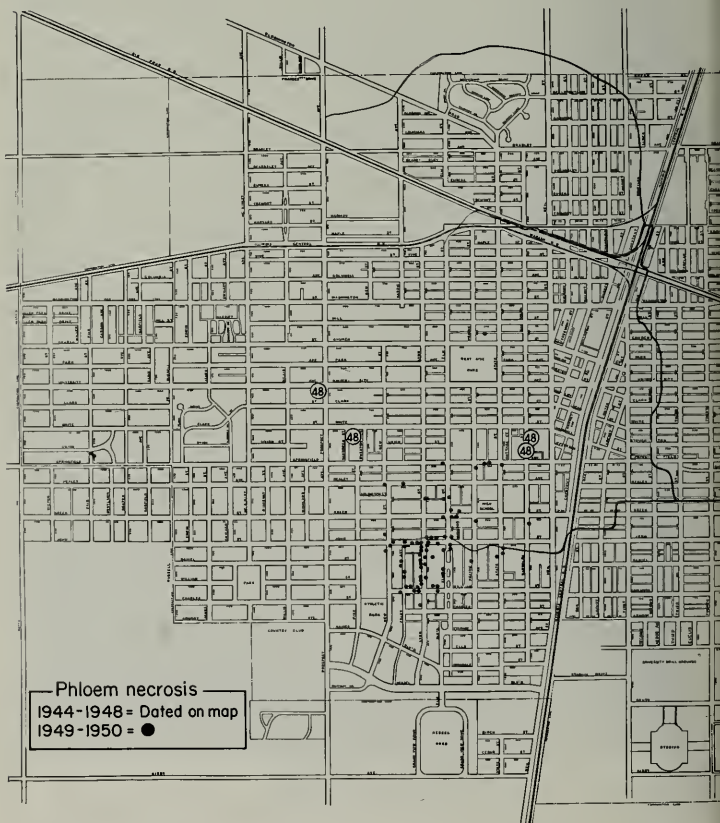


Fig. 4.—Distribution of 16 Champaign-Urbana, Illinois, elms affected by phloem necrosis from 1944 through 1948 (dated according to year when symptoms appeared) and of 412



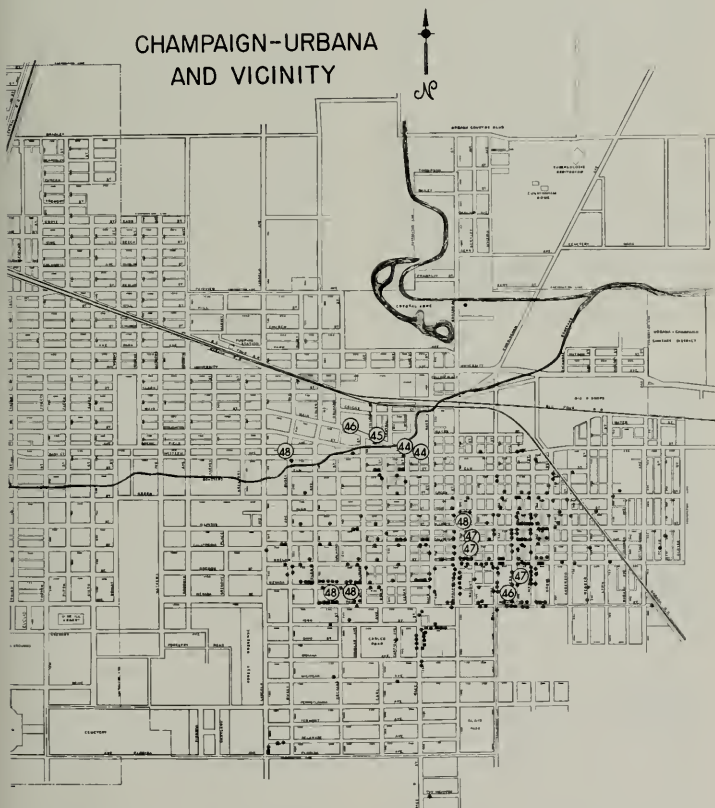
completed until early July and the second survey was not completed until early October. Each survey was made by observing all elms visible from the street while traveling by automobile. This type of survey necessitated driving 200 miles [320 km] of streets, which required a maximum driving time of 24 hours. We used our personal automobile, and the surveying was done in the evenings and on Saturdays.

The presence of phloem necrosis dur-

ing the years of low initial incidence, 1944–1948, was determined by examining the inner phloem for the butterscotch color and wintergreen odor characteristic of the disease.

Dutch elm disease during the years of low initial incidence, 1951–1952, was identified by a laboratory culture test for the fungus.

Following the years of low initial incidence, each disease was recognized by foliage symptoms. Phloem necrosis-



elms affected by phloem necrosis in 1949 and 1950 (black dots). Some dots represent more than one tree where the elms were less than 30 feet [9 m] apart.

affected trees commonly show yellowing and wilting of leaves over the entire crown (Fig. 1), while Dutch elm disease-affected trees frequently have wilted foliage only on one or a few branches (Fig. 2). However, some Dutch elm disease-affected trees show general wilting on the entire crown. Leaves on such trees usually display less yellowing but more rapid browning and wilting than leaves show on phloem necrosis-affected trees. When there was doubt as to which disease was involved, a diagnosis was usually made by examining wood and bark samples. Also, the accuracy of diagnosis by observation from an automobile was tested by examining an occasional elm for wood and bark symptoms.

Data were recorded as to which disease was involved and whether a tree was wilting or dead. The stage or amount of wilt evident at the time of each survey was indicated by listing each tree showing the early, intermediate, or late stage of wilt. All dead elms were listed as dead, and all trees were listed by street address and whether on public or private property.

## RESULTS

### INITIAL SPREAD OF PHLOEM NECROSIS

Following the discovery in Urbana of phloem necrosis in two elms in 1944, one elm was affected by this disease in 1945, two in 1946, three in 1947, and eight in 1948 (Fig. 3). The tree affected in 1945 was about 300 feet [90 m] west of the two elms affected in 1944. Of the two elms affected in 1946, one was about 400 feet [120 m] farther west and one was about 1,900 feet [580 m] southeast of the elms affected in 1944 and 1945. Of the three elms affected in 1947, one was about 150 feet [45 m] northeast of a tree affected in 1946. The other two were on a line between trees affected in 1944 and 1946 and over 600 feet [180 m] from the nearest previously diseased elm. One of the eight elms affected

in 1948 was about 150 feet [45 m] north of an elm affected in 1947. The remaining seven elms were scattered west of previously affected trees. They ranged from about 700 to 8,000 feet [210–2,440 m] from the nearest previously diseased elms. Although the direction of the spread of phloem necrosis was generally west and south, each diseased tree was surrounded by numerous healthy elms.

The two elms that showed phloem necrosis symptoms in 1944 were in the 200 block of West Main Street in Urbana. They were among the oldest elms in the city. They were surrounded by numerous elms except for the three-square-block area of the business district of Urbana, starting in the 100 block of West Main Street. East of the business district, elms were abundant to the east city limit. Each of the 14 elms that became diseased from 1945 through 1948 represented a separate infection center, as none of them was within root-grafting distance of other affected trees (Himelick & Neely 1962; Verrall & Graham 1935). Each diseased tree was surrounded by healthy elms.

In 1949 and 1950 the number of diseased trees increased rapidly in Urbana. The disease was confined almost entirely to an area in south-central Urbana approximately 12 blocks square and extending south from the 200 block of West Main Street, the location of the two elms that first contracted phloem necrosis. By 1951, when Dutch elm disease was first found in Urbana, phloem necrosis was concentrated in this 12-block area and scattered at random in all directions around 7 of the 12 previously diseased Urbana elms, as shown in Fig. 4. The disease had not invaded an area six blocks wide along the west boundary of Urbana. In Champaign the disease appeared in the 700 block of South Lynn Street in 1949. By 1951 it had spread to many surrounding elms, as described subsequently. A few scattered elms north of this area and two elms within

two blocks of the west boundary of Champaign were also diseased. No elms were affected within the immediate areas surrounding the four Champaign elms that became diseased before 1949.

#### APPEARANCE AND SPREAD OF PHLOEM NECROSIS IN THE 700 BLOCK OF SOUTH LYNN STREET, CHAMPAIGN, 1949-1951

Only four elms showed symptoms of phloem necrosis in the entire city of Champaign in 1948, the year before the disease appeared in the 700 block of South Lynn Street. The nearest of these four elms was over 1,200 feet [370 m] northeast of the South Lynn Street 700 block (Fig. 4). Of the 36 elms in that block, 23 were on the west side of the street and 13 were on the east side. On the west side 21 were parkway trees and 2 were on private property, while 8 were parkway trees and 5 were on private property on the east side of the street. Each of the 21 parkway elms and 2 private-property elms on the west side of the street were within root-grafting distance of one or more elms (Fig. 5). The number of elms having phloem necrosis each year and the month in which symptoms were first observed are shown in Fig. 5.

On South Lynn Street, 8 elms wilted in 1949, 21 in 1950, and 7 in 1951. Of the eight elms that wilted in 1949, seven were on the west side of the street, and each was separated from the others by at least one elm that did not show wilt symptoms in 1949. Of 11 closely planted parkway elms on the west side of the street, every other one (5 trees) wilted in 1949, and the remaining 6 trees wilted in 1950.

The wilting of eight elms in 1949 suggests that the elm leafhopper, vector of the phloem necrosis MLO, fed extensively on the trees in this limited area before 1949. Since all 36 elms wilted within 3 years, all transmission of the MLO may have been by the elm leafhopper. However, most of the

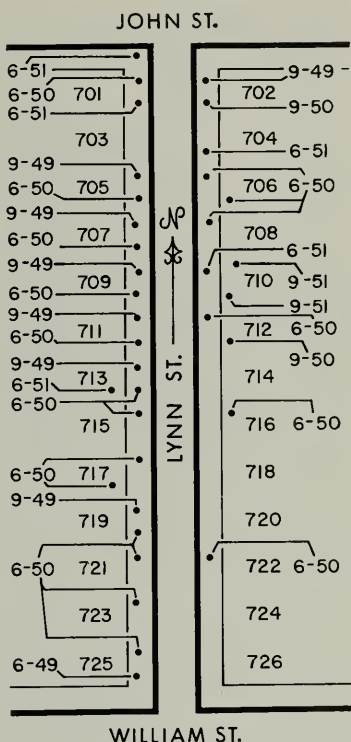


Fig. 5.—The spread of phloem necrosis, 1949-1951, in the 700 block of South Lynn Street, Champaign, Illinois.

elms that wilted in 1950 and 1951 were adjacent to elms that had wilted during the previous year, and they could have become infected through root-graft transmission of the MLO. Only three of the 36 elms were beyond root-grafting distance of other elms.

#### SPREAD OF PHLOEM NECROSIS IN 1951 AND 1952 AND INFLUENCE OF PHLOEM NECROSIS ON THE EARLY SPREAD OF DUTCH ELM DISEASE

The spread of phloem necrosis in Champaign-Urbana in 1951 and 1952 occurred among elms both within and

Table 2.—Spread of phloem necrosis in Champaign-Urbana, Illinois, in 1951 and 1952 in relation to the location of elms affected by phloem necrosis in the previous year.

Year	Diseased Elms	Elms Within Root-Grafting Distance of Previously Diseased Trees		Elms Beyond Root-Grafting Distance of Previously Diseased Trees	
		Number	Percent	Number	Percent
1951	359	116	32.3	243	67.7
1952	555	186	33.5	369	66.5
<i>Total or percent</i>	<i>914</i>	<i>302</i>	<i>33.0</i>	<i>612</i>	<i>67.0</i>

beyond root-grafting distance of previously affected trees. Of the 914 elms affected by phloem necrosis in 1951 and 1952, 33 percent were within and 67 percent were beyond root-grafting distance of previously affected trees (Table 2). The affected elms that were beyond root-grafting distance of previously affected elms were widely and randomly scattered at distances of 50 feet [15 m] to more than 1,000 feet [300 m] from previously diseased trees.

With the appearance of Dutch elm disease in a single elm in the 800 block of West Pennsylvania Avenue in southwest Urbana in 1951, our data on the incidence of phloem necrosis were examined to determine the influence of phloem necrosis on the appearance and early spread of Dutch elm disease. The relationship of phloem necrosis to the appearance and early spread of Dutch elm disease is indicated by the fact that phloem necrosis-affected elms can harbor both the smaller European elm bark beetle and the Dutch elm disease fungus. Data originally gathered in Urbana by E. B. Himelick in 1952 showed that 8 of 40 elms dying from phloem necrosis were infested with the bark beetles and the fungus (Campana 1954:358). Apparently the Dutch elm disease fungus had been introduced into the phloem necrosis-affected elms by the bark beetles.

The population of the smaller European elm bark beetle is largely determined by the amount of elm material available for colonization. Since there was no community-wide program for the control of either disease in Champaign-Urbana, most of the diseased

trees were left standing for several weeks, months, or a year or more after they had died. These trees served as abundant colonizing locations for the bark beetles. The number of standing dead elms in June and September in 1951, 1952, and 1953 (Table 3) was greater than the number of elms wilting from phloem necrosis in these same months except in June 1951. Under these conditions millions of the smaller European elm bark beetles were present in the area and were potential carriers of the Dutch elm disease fungus.

Table 3.—Number of phloem necrosis-affected elms, wilting and dead, standing in Champaign-Urbana, Illinois, in June and September 1951, 1952, and 1953.

Year	Elms Dead from Phloem Necrosis		Elms Wilting from Phloem Necrosis	
	June	September	June	September
1951	213	187	218	141
1952	324	558	239	316
1953	589	441	193	195
<i>Total</i>	<i>1,126</i>	<i>1,186</i>	<i>650</i>	<i>652</i>

#### APPEARANCE OF DUTCH ELM DISEASE AND LOCATIONS OF ELMs HAVING DUTCH ELM DISEASE, 1951-1953

Dutch elm disease first appeared in the Champaign-Urbana area in 1951 when a single affected elm was found in the 800 block of West Pennsylvania Avenue in southwest Urbana. We verified the disease by culturing the fungus from samples of the brown, discolored sapwood of wilted branches. Phloem necrosis also spread to this immediate area in 1951 when two elms showed symptoms of that disease.

Eleven elms were killed by Dutch elm disease in the Champaign-Urbana area in 1952. Of these 11 elms, 3 were adjacent to elms that were wilting

CHAMPAIGN-URBANA  
AND VICINITY

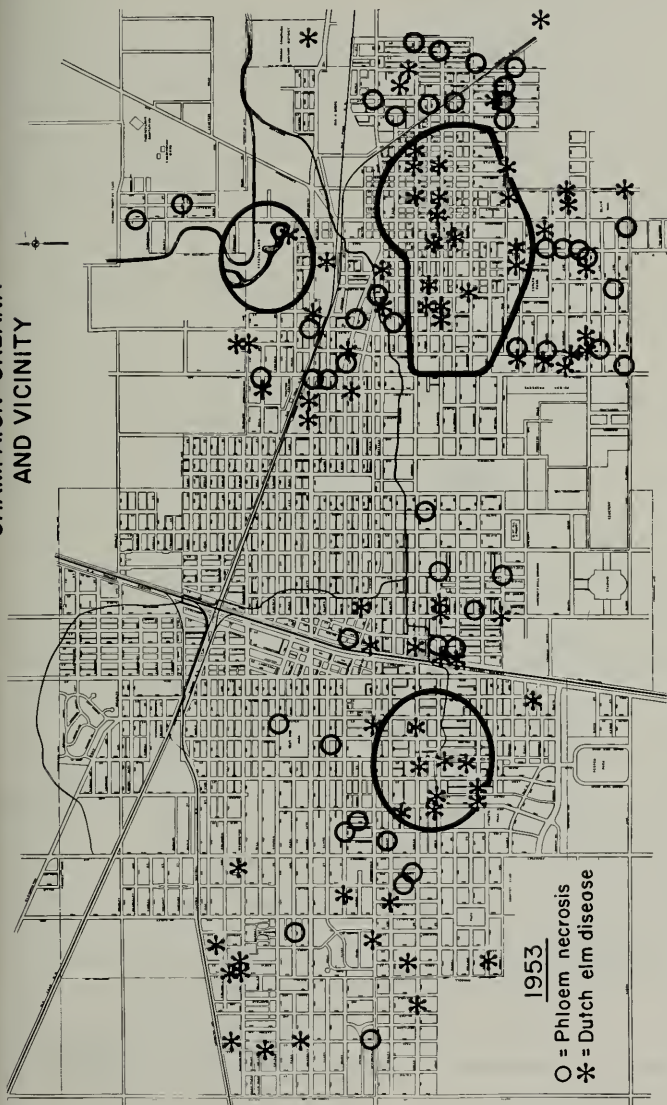


Fig. 6.—Distribution of elms affected by phloem necrosis and Dutch elm disease in Champaign-Urbana, Illinois, in 1953. The three areas enclosed by heavy lines show locations of Dutch elm disease-affected elms in areas where phloem necrosis was abundant.



from or had been killed by phloem necrosis. Of these three, one was adjacent to a phloem necrosis-affected elm that wilted in 1950 and 1951 and was dead by 1952. One was adjacent to an elm that wilted in 1950, and one was adjacent to two elms. One of these two elms wilted in 1950, and the other wilted in 1951. The remaining eight elms affected by Dutch elm disease in 1952 were isolated trees that were not adjacent to phloem necrosis-affected elms or to the one elm affected by Dutch elm disease in 1951.

The locations of 164 elms affected by Dutch elm disease in 1953 and their relation to phloem necrosis-affected elms are shown in Fig. 6 (some locations represent more than one tree). Twenty-seven locations of Dutch elm disease-affected elms were in areas where phloem necrosis was abundant, as indicated by the three areas enclosed by heavy lines in Fig. 6. Ten other locations were immediately adjacent to one or more phloem necrosis-affected elms. The locations of the remaining 41 Dutch elm disease-affected trees

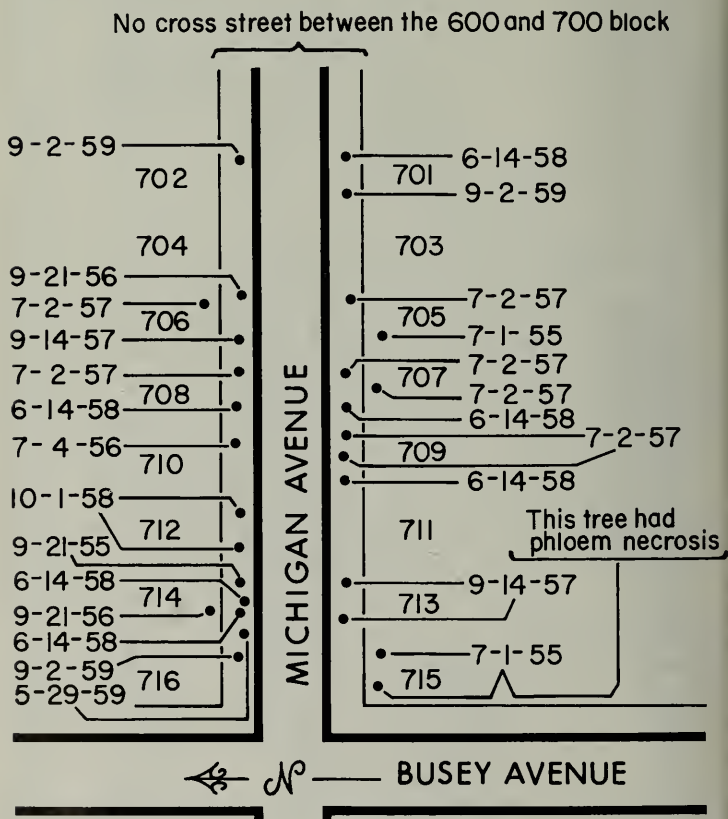


Fig. 7.—The spread of Dutch elm disease, 1955–1959, in the 700 block of West Michigan Avenue, Urbana, Illinois.



were not adjacent to phloem necrosis-affected elms but were widely scattered throughout much of the Champaign-Urbana area.

Only one of the 176 elms affected by Dutch elm disease during this 3-year period, 1951-1953, was within root-grafting distance of an elm previously affected by Dutch elm disease. This one elm wilted in 1953 and was adjacent to an elm that wilted in 1952. Therefore, the Dutch elm disease fungus was carried to the remaining 175 elms by elm bark beetles.

#### SPREAD OF DUTCH ELM DISEASE IN THE 700 BLOCK OF WEST MICHIGAN AVENUE, URBANA, 1955-1959

Elms began dying in the 700 block of West Michigan Avenue, Urbana, in 1955, when four elms wilted, three from Dutch elm disease and one from phloem necrosis. Elms affected by Dutch elm disease before 1955 within one block of this area were: one in 1951, two in 1953, and three in 1954. Phloem necrosis did not occur within one block of this area before 1955.

There were 29 American elms (23 in the parkway and 6 on private property) in this area in June 1955 when the first 3 showed wilt symptoms of Dutch elm disease. The location of each tree is indicated in Fig. 7. The date is shown when wilt symptoms were first observed on each tree. The annual loss of elms is given in Table 4.

Of the 28 elms killed in this block by Dutch elm disease in 5 years, more (10 trees) were killed in the third year than in any other year of the study. No elm within root-grafting distance of previously diseased trees showed wilt symptoms in the second year. Thirteen (46 percent) of the trees were within root-grafting distance of previously diseased trees. Therefore, they may have become infected through roots grafted to those of previously diseased elms. The remaining 15 elms (54 percent), not within root-grafting distance of previously diseased trees, became infected

Table 4.—Elms killed annually by Dutch elm disease in the 700 block of West Michigan Avenue, Urbana, Illinois, 1955-1959.

Year	Elms Killed by Dutch Elm Disease			Elms Within Root-Grafting Distance of Previously Diseased Trees			Elms Beyond Root-Grafting Distance of Previously Diseased Trees		
	Residual Population	Number	Percent	Original Population	Residual Population	Percent	Number	Original Population	Residual Population
1955	28 <sup>a</sup>	3	11	11	11	..	3	11	11
1956	25	3	11	12	12	..	3	11	12
1957	22	10	36	45	23	..	5	18	23
1958	12	8	28	67	50	..	2	7	17
1959	4	4	14	100	50	..	2	7	50
Total or percent		28	100		46		15	54	

<sup>a</sup> One elm died from phloem necrosis in 1955 and is not included in this table.

through insect transmission of the fungus.

SPREAD OF PHLOEM NECROSIS AND DUTCH ELM DISEASE ON SPRINGFIELD AVENUE, CHAMPAIGN, 1955-1959

Elms in a six-block section of East Springfield Avenue, Champaign, between First and Wright Streets, began dying in 1955 when one elm wilted from Dutch elm disease. Phloem necrosis did not appear in this area until 1957, when one elm contracted that disease. Several elms within three blocks of Springfield Avenue were attacked by each of these diseases before 1955. Two elms died from phloem necrosis in 1953, one located two blocks northwest of the

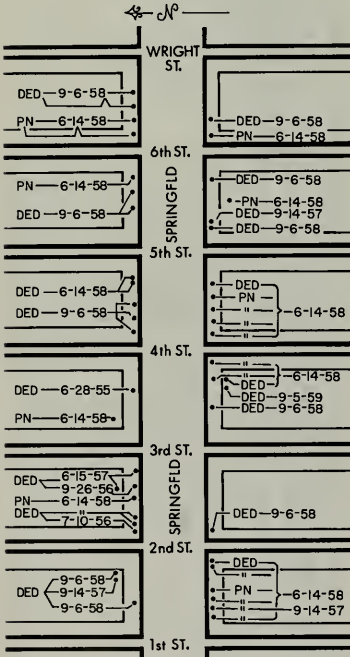


Fig. 8.—The spread of phloem necrosis (PN) and Dutch elm disease (DED) on East Springfield Avenue, Champaign, Illinois, 1955-1959.

Table 5.—Elms killed annually by phloem necrosis and Dutch elm disease in the 100-600 blocks of East Springfield Avenue, Champaign, Illinois, 1955-1959.

Year	Elms Killed by Phloem Necrosis			Elms Killed by Dutch Elm Disease			Elms Killed by Both Diseases		
	Residual Elm Population	Number	Percent	Number	Percent	Residual Population	Number	Percent	Original Population
1955	47	..	..	1	2	2	1	2	2
1956	46	..	..	2	4	4	2	4	4
1957	44	1	2	4	9	9	5	11	11
1958	39	16	34	22	47	56	38	81	97
1959	1	..	..	1	2	100	1	2	100
Total or percent		17	36	30	64		47	100	

100 block and one located two and one-half blocks south of the 600 block of East Springfield Avenue. Twelve elms died from Dutch elm disease, two in 1953 and ten in 1954. One of the two elms that died in 1953 was two blocks west and one was one block north of the 100 block of East Springfield Avenue. Of the 10 elms that died in 1954, 7 were one block distant from the 100 and 200 blocks, and 3 were two blocks from the 400 block of East Springfield Avenue.

The parkway along this six-block stretch was lined with 40 Moline elms in 1950. Each tree was approximately 1 foot [0.3 m] in trunk diameter. Seven larger American elms along the same section were located on private property. The locations of these 47 elms are indicated in Fig. 8. The 25 elms that wilted in 1955 on streets that cross East Springfield Avenue were beyond root-grafting distance of the elms along Springfield Avenue. All 47 elms on

East Springfield Avenue became affected by phloem necrosis or Dutch elm disease and died within 5 years, 1955–1959.

Of the 47 elms killed in 5 years along East Springfield Avenue, Champaign, 17 (36 percent) were killed in 2 years by phloem necrosis, while 30 (64 percent) were killed in 5 years by Dutch elm disease. The disease involved and the year that each tree became diseased are shown in Table 5.

A rapid increase in the number of trees affected by each disease occurred in the year following the appearance of phloem necrosis and in the third year following the appearance of Dutch elm disease. Two of the trees killed by phloem necrosis on the south side of the 100 block of East Springfield Avenue in 1958 were within root-grafting distance of a tree killed by phloem necrosis in 1957 (Fig. 9). Six of the trees on East Springfield Avenue killed by Dutch elm disease between 1955 and



Fig. 9.—Moline elms on the south side of the 100 block of East Springfield Avenue, Champaign, Illinois. The first four elms on the right were killed by phloem necrosis. The fifth elm and one elm east of this fifth tree, removed before the picture was taken, were killed by Dutch elm disease. The second elm from the right died in 1957, and the others died in 1958. (Photo by W. E. Clark)

1959 were within root-grafting distance of trees killed by Dutch elm disease in the previous 1 or 2 years. Three of these six elms were on the north side of the 200 block, one on the north side of the 100 block, one on the south side of the 300 block, and one on the south side of the 500 block.

Since 39 of the 47 elms in this area were not within root-grafting distance of previously diseased trees, the spread of each disease occurred mainly by insect transmission of each causal agent.

#### PHLOEM NECROSIS-AFFECTED ELMS THAT LATER SHOWED SYMPTOMS OF DUTCH ELM DISEASE

Some elms affected by phloem necrosis subsequently became affected by Dutch elm disease before dying. The number of elms that showed phloem necrosis symptoms followed by Dutch elm disease symptoms from 1954 to 1960 is listed in Table 6. During this 7-year period 1,234 trees were affected by phloem necrosis and 10,714 trees were affected by Dutch elm disease. The data are arranged according to the time between the first appearance of phloem necrosis symptoms and the subsequent appearance of Dutch elm disease symptoms.

Of the 153 elms affected by both diseases, 28 (18.3 percent) were affected by Dutch elm disease in Sep-

tember following the appearance of phloem necrosis symptoms in the previous June, 123 (80.4 percent) in the year following the appearance of phloem necrosis symptoms, and only two (1.3 percent) in the second year following the appearance of phloem necrosis symptoms. In general, the percentage of phloem necrosis-affected elms that subsequently showed Dutch elm disease increased as the number of elms affected by Dutch elm disease increased. Many elms that become infected with the Dutch elm disease fungus in June wilt during the same growing season. Therefore, it is not surprising that 28 elms that showed phloem necrosis symptoms in June showed Dutch elm disease symptoms by the following September. Elms which had been wilting from phloem necrosis in June and were wilting from Dutch elm disease in September most likely became infected by the Dutch elm disease fungus in June, when phloem necrosis symptoms were already evident.

#### INCIDENCE OF PHLOEM NECROSIS AND DUTCH ELM DISEASE IN CHAMPAIGN-URBANA, 1944-1972

To determine the incidence of phloem necrosis and Dutch elm disease in Champaign-Urbana, the number of elms affected annually by each disease

Table 6.—Phloem necrosis-affected elms in Champaign-Urbana, Illinois, that subsequently contracted Dutch elm disease, 1954-1960.

Year	Elms Affected by Phloem Necrosis	Elms Showing Dutch Elm Disease Symptoms			Phloem Necrosis-Affected Elms That Later Showed Dutch Elm Disease Symptoms	
		Same Year*	1 Year Later	2 Years Later	Number	Percent
1954	179	..	13	..	13	7.3
1955	123	..	..	..	..	....
1956	60	1	5	..	6	10.0
1957	368	1	42	2	45	12.2
1958	344	25	45	..	70	20.3
1959	148	..	17	..	17	11.5
1960	12	1	1	..	2	16.7
Total or percent	1,234	28	123	2	153	12.4

\* Trees listed in this column showed phloem necrosis symptoms in the June survey and Dutch elm disease symptoms in the following September survey.

Table 7.—Elms killed by phloem necrosis and Dutch elm disease in Champaign-Urbana, Illinois, from 1944 through 1972.

Year	Residual Elm Population	Elms Killed Annually by Phloem Necrosis			Elms Killed Annually by Dutch Elm Disease			Elms Killed Annually by Both Diseases		
		Number	Percent of Original Population	Percent of Residual Population	Number	Percent of Original Population	Percent of Residual Population	Number	Percent of Original Population*	Percent of Residual Population*
1944	14,103	2	0.01	0.01	...	...	...	2	0.01	0.01
1945	14,101	1	0.01	0.01	...	...	...	1	0.01	0.01
1946	14,100	2	0.01	0.01	...	...	...	2	0.01	0.01
1947	14,098	3	0.02	0.02	...	...	...	3	0.02	0.02
1948	14,095	8	0.06	0.06	...	...	...	8	0.06	0.06
1949	14,087	99	0.70	0.70	...	...	...	99	0.70	0.70
1950	13,988	313	2.22	2.24	...	...	...	313	2.22	2.24
1951	13,675	359	2.55	2.63	11	0.01	0.01	360	2.55	2.63
1952	13,315	555	3.94	4.17	11	0.08	0.08	566	4.01	4.25
1953	12,749	388	2.75	3.04	164	1.16	1.29	552	3.91	4.33
1954	12,197	179	1.27	1.47	694	4.92	5.69	873	6.19	7.16
1955	11,324	123	0.87	1.09	1,805	12.80	15.94	1,928	13.67	17.03
1956	9,396	60	0.43	0.64	1,836	13.02	19.54	1,896	13.44	20.18
1957	7,500	368	2.61	4.91	2,116	15.00	28.21	2,484	17.61	33.12
1958	5,016	344	2.44	6.86	1,770	12.55	35.29	2,114	14.99	42.15
1959	2,902	148	1.05	5.10	1,804	12.79	62.16	1,952	13.84	67.26
1960	950	12	0.09	1.26	689	4.89	72.53	701	4.97	73.79
1961	249	3	0.02	1.20	119	0.84	47.79	122	0.86	49.00
1962	127	1	0.01	0.79	31	0.22	24.41	32	0.23	25.20
1963	95	4	0.03	4.21	9	0.06	9.47	13	0.09	13.68
1964	82	4	0.03	4.88	1	0.01	1.22	5	0.04	6.10
1965	77	1	0.01	1.30	4	0.03	5.19	5	0.04	6.49
1966	72	1	0.01	1.39	1	0.01	1.39	2	0.01	2.78
1967	70	3	0.02	4.29	0	...	...	3	0.02	4.29
1968	60 <sup>b</sup>	2	0.01	3.33	1	0.01	1.67	3	0.02	5.00
1969	57	0	...	...	1	0.01	1.75	1	0.01	1.75
1970	56	3	0.02	5.36	0	...	...	3	0.02	5.36
1971	53	5	0.04	9.43	0	...	...	5	0.04	9.43
1972	48	3	0.02	6.25	5	0.04	10.42	8	0.06	16.67
Total or percent		2,994	21.23		11,062	78.44		14,056	99.67	

\* Some percentages in this column are not exact totals of the corresponding percentages in preceding columns because all percentages have been rounded to two decimal places.

<sup>b</sup> Seven trees that were not diseased but were severely damaged by ice in January 1968 were removed. Healthy trees removed because of construction or any other cause have not been included in this study.



was recorded from 1944, when phloem necrosis first appeared, through 1972. The number of elms affected annually and the percentages of the original and residual elm populations lost each year are recorded in Table 7. The percentages of the original elm population lost annually to each disease are illustrated in Fig. 10. The percentages of the residual elm population lost annually to each disease are illustrated in Fig. 11.

### Phloem Necrosis

A rapid increase in the number of elms affected by phloem necrosis did not occur until 1949, 5 years after the disease had first appeared in two Urbana elms. The number of elms affected by phloem necrosis in Champaign-Urbana increased annually until 1952, when 555 were affected. Following 1952 the number of phloem necrosis-diseased trees decreased annually until 1956, when only 60 elms were killed. This decrease was followed by an increase to 368 affected trees in 1957. After 1957 the number of phloem necrosis-diseased trees decreased rapidly until 1960, when only 12 elms were

affected. From 1961 through 1972 only one to five elms were affected by phloem necrosis annually except in 1969, when no phloem necrosis occurred. From 1944 through 1972, a period of 29 years, 2,994 elms were killed by phloem necrosis.

The two peak periods of elm deaths from phloem necrosis occurred in 1952 and 1957 (Fig. 10). The cause for the high death rate of elms in 1952 and the subsequent decrease in the incidence of phloem necrosis through 1956 was not determined. However, four conditions that may have been involved were (1) the rapid increase in the incidence of Dutch elm disease, (2) the reduction in the elm population, (3) the time required for symptoms of phloem necrosis to appear following infection, and (4) drought conditions from 1952 through 1955.

The incidence of Dutch elm disease increased from 11 trees in 1952 to 1,805 trees in 1955. During this period Dutch elm disease reduced the elm population by 2,674 trees, or 20 percent of the elm population of 1952.

The time required for wilt symptoms to appear following infection is longer

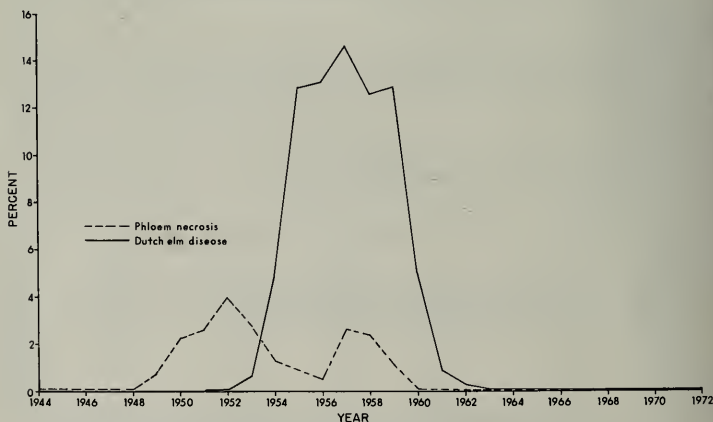


Fig. 10.—Annual percentages of the original population of 14,103 elms lost to phloem necrosis and Dutch elm disease in Champaign-Urbana, Illinois, 1944–1972.



for phloem necrosis than for Dutch elm disease. Phloem necrosis-affected elms do not show foliage symptoms for at least 1 year following infection, while many Dutch elm disease-affected elms show foliage symptoms in the year when infection occurs.

Drought conditions that prevailed from 1952 through 1955, especially in 1953 and 1954, may have caused a reduction in the elm leafhopper population, since this insect is adversely affected by such conditions. Precipitation for the 5-month growing season, May through September, was 7.89 inches [200.41 mm] below normal in 1953 and 4.19 inches [106.41 mm] below normal in 1954. Total precipitation was 10.34 inches [262.64 mm] below normal in 1953 and 6.73 inches [170.94 mm] below normal in 1954 (Carter 1955:40). Collection records of the Section of Faunistic Surveys and Insect Identification, Illinois Natural History Survey, show that the populations of leafhoppers in general were drastically reduced during these drought years and that the elm leafhopper has never been collected in abundance in Illinois.

The increase in the incidence of

phloem necrosis from 1957 through 1959 may have been influenced mainly by an increase in the elm leafhopper population, which might be expected in years of near-normal rainfall. Following 1959 the incidence of phloem necrosis decreased to very low levels during the period of rapid decline in the residual elm population. Only 7 percent of the original elm population remained by 1960.

### Dutch Elm Disease

A rapid increase in the number of elms affected by Dutch elm disease started in 1953, 2 years after the disease first appeared in Urbana in a single elm. The number of elms affected annually by Dutch elm disease increased until 1957, when 2,116 trees were affected. During the 5-year period 1955–1959, the annual loss of elms to Dutch elm disease was 1,770–2,116, with a total loss of 9,331 trees. This number was 82.4 percent of the residual elm population of 11,324 trees in the spring of 1955, or 66.2 percent of the original elm population of 14,103 trees in 1944.

The peak incidence of Dutch elm disease (Fig. 10) occurred in 1957, 6

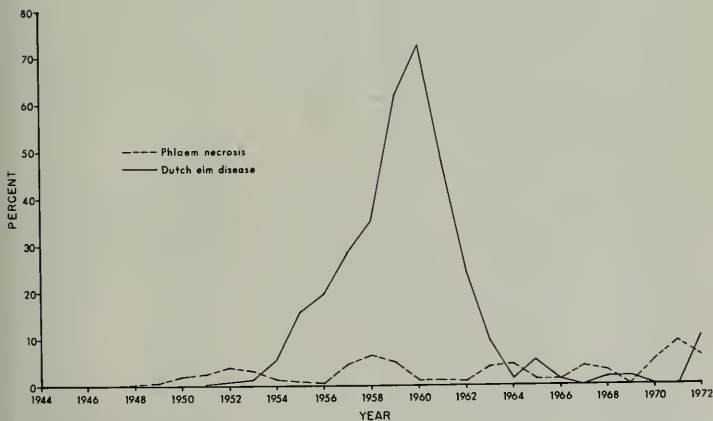


Fig. 11.—Annual percentages of the residual population of elms lost to phloem necrosis and Dutch elm disease in Champaign-Urbana, Illinois, 1944–1972.

years after the disease first appeared in the area. The number of elms killed in 1957 was 2,116, or 15 percent of the original elm population and 28.21 percent of the residual elm population. Following 1959 the residual elm population decreased rapidly until 1963, when only 95 healthy elms remained and only 9 were killed by Dutch elm disease. With the rapid decline in the elm population, the incidence of Dutch elm disease also declined drastically. From 1964 to 1969 only one to four trees (none in 1967) became affected by this disease annually. No elms were affected in 1970 and 1971, but five elms were affected in 1972.

Figure 10 shows that the incidence of Dutch elm disease increased more rapidly, reached a much higher peak, and decreased more rapidly than did the incidence of phloem necrosis. Additionally, only one peak period of elm deaths from Dutch elm disease occurred, while there were two peak periods of elm deaths from phloem necrosis.

#### Effect of Each Disease on the Residual Population of Elms

The annual loss of elms from each disease in relation to the residual elm population is illustrated in Fig. 11. The annual loss from phloem necrosis fluctuated from year to year, reaching five peaks of 5 percent or more of the residual elm population. The highest peak (9.43 percent) occurred in 1971, when the residual elm population was only 53 trees. The next highest peak occurred in 1958, when the residual elm population was 5,016 trees.

Following the appearance of Dutch elm disease in 1951, the percentage of the residual elm population killed annually by this disease increased rapidly until 1960. In 1960 Dutch elm disease killed 689 trees (72.53 percent) of the residual elm population of 950 trees. Following 1960 the annual loss of trees in the residual elm population decreased rapidly until 1964 when only

1 elm (1.22 percent) of the residual population of 82 was killed by Dutch elm disease.

#### Accumulated Percentages of Elms Killed by Each Disease, 1944-1972

The accumulated percentages of elms killed by each disease are given in Table 8 and illustrated in Fig. 12. The loss of elms from each disease follows a sigmoid curve. Less than 10 percent of the elm population was killed by both diseases from 1944 through 1952, a period of 9 years. Phloem necrosis was present throughout the 9-year period, but Dutch elm disease was present for only 2 years. During the second 9-year period, 1953-1961, both diseases killed more than 89 percent of the

Table 8.—Accumulated percentages of elms killed by phloem necrosis and Dutch elm disease in Champaign-Urbana, Illinois, from 1944 through 1972.

Year	Percent of Elms Killed by	
	Phloem Necrosis	Dutch Elm Disease
1944	0.01	...
1945	0.02	...
1946	0.04	...
1947	0.06	...
1948	0.11	...
1949	0.32	...
1950	3.03	...
1951	5.58	0.01
1952	9.52	0.09
1953	12.27	1.25
1954	13.54	6.17
1955	14.41	18.97
1956	14.83	31.99
1957	17.44	46.99
1958	19.88	59.54
1959	20.93	72.33
1960	21.02	77.22
1961	21.04	78.06
1962	21.05	78.28
1963	21.07	78.34
1964	21.10	78.35
1965	21.11	78.38
1966	21.12	78.39
1967	21.14	78.39
1968	21.15	78.39
1969	21.15	78.40
1970	21.17	78.40
1971	21.21	78.40
1972	21.23	78.44

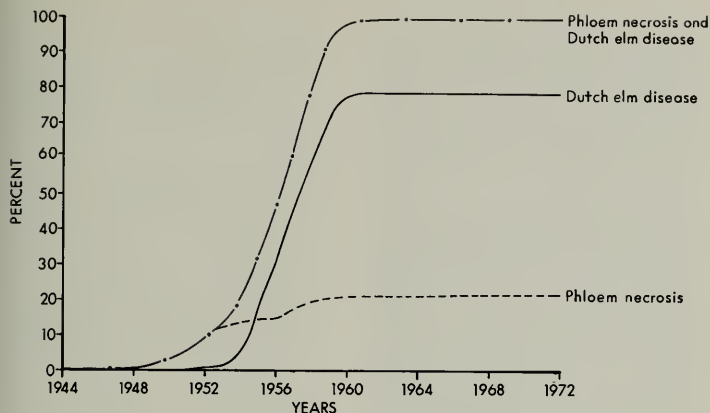


Fig. 12.—Accumulated percentages of the original population of 14,103 elms lost each year to phloem necrosis and Dutch elm disease in Champaign-Urbana, Illinois, 1944–1972.

original elm population. With less than 1 percent of the elms remaining after 18 years, the annual loss became a few trees. Phloem necrosis killed 2,994 elms during the 29-year period, 1944–1972, while Dutch elm disease killed 11,062 elms during the 22-year period, 1951–1972. Although no elms showed symptoms of Dutch elm disease in 1970 or 1971, five trees were killed by the disease in 1972. Of the original population of 14,103 elms in 1944, all but 40 had been killed by the fall of 1972, a period of 29 years.

#### TIME OF YEAR IN WHICH ELMS DIED FROM PHLOEM NECROSIS AND DUTCH ELM DISEASE

Starting in 1951 two surveys were made annually to record the number of elms affected by phloem necrosis and by Dutch elm disease. The first survey was made in the early part of the growing season, usually in June. The second survey was made in the late part of the growing season, usually in September. These surveys are referred to as the June and September surveys.

Each year data were obtained on the

Table 9.—Elms showing disease symptoms in June and September surveys, Champaign-Urbana, Illinois, 1955–1961.

Year	Elms Having Phloem Necrosis Symptoms			Elms Having Dutch Elm Disease Symptoms			Total Diseased Elms	Standing Dead Elms	
	June Survey	September Survey	Total	June Survey	September Survey	Total		June Survey	September Survey
1955	40	81	121	1,059	746	1,805	1,926	86	133
1956	21	39	60	1,162	674	1,836	1,896	160	528
1957	44	324	368	1,159	957	2,116	2,484	255	520
1958	217	127	344	1,049	721	1,770	2,114	447	1,323
1959	58	90	148	1,116	688	1,804	1,952	1,064	1,509
1960	4	8	12	496	193	689	701	608	341
1961	2	1	3	92	27	119	122	...	...
Total	386	670	1,056	6,133	4,006	10,139	11,195	2,620	4,354

number of elms affected by each disease in each of the two survey periods. No affected elm was included in the data of more than one survey. The numbers of elms affected by each disease at the time of each June and September survey from 1955 through 1961 are recorded in Table 9.

Of the 1,056 elms affected by phloem necrosis during this 7-year period, 386 (36.6 percent) showed symptoms in June, and 670 (63.4 percent) showed symptoms in September. Of the 10,139 elms affected by Dutch elm disease, 6,133 (60.5 percent) showed symptoms in June, and 4,006 (39.5 percent) showed symptoms in September. Of the 6,974 dead elms standing at the time of the June and the September surveys during the years 1955-1960, 2,620 (37.6 percent) were standing in June and 4,354 (62.4 percent) were standing in September.

#### PERIOD OF TIME IN WHICH ELMS DIED FOLLOWING THE APPEARANCE OF FOLIAGE WILT OF PHLOEM NECROSIS OR DUTCH ELM DISEASE

Not all elms affected by phloem necrosis or Dutch elm disease die in the same growing season in which foliage wilt first appears. Some elms wilt during two, and occasionally three, growing seasons before they die; some elms that have shown no foliage wilt die during the winter. Data on 231 elms affected by phloem necrosis, 3,908 elms affected by Dutch elm disease, and 820 elms that died but showed no foliage wilt are given in Table 10. The data cover the growing seasons of 1955 through 1960. During this period most diseased elms were not removed until after they were dead. This practice made it possible to record the period of time in which the diseased trees died.

Of the 231 phloem necrosis-affected elms, 143 (61.9 percent) died in the year following the appearance of wilt. Only 87 (37.7 percent) died in the year that wilt appeared, and only 1 (0.4 percent) lived until the second year fol-

Table 10.—The period of time in which elms died following the appearance of wilt symptoms of phloem necrosis or Dutch elm disease, Champaign-Urbana, Illinois, 1955-1960.

Year	Elms Showing Phloem Necrosis Wilt That Died					Elms Showing Dutch Elm Disease Wilt That Died					Elms That Died in Winter	
	Same Year		1 Year Later		2 Years Later	Same Year		1 Year Later		2 Years Later	June	September
	Wilted in June	Not Wilted in June	Wilted in June	Not Wilted in June		Wilted in June	Not Wilted in June	Wilted in June	Not Wilted in June			
1955	13	2	..	..	..	247	119	..	..	..	..	79
1956	..	..	3	..	..	94	102	37	9	..	..	66
1957	..	17	10	..	..	235	227	39	19	3	2	89
1958	11	21	47	19	..	426	736	80	84	2	1	169
1959	14	9	30	17	1	462	302	205	107	9	1	273
1960	..	..	16	1	..	101	83	137	36	3	..	144
Total	38	49	106	37	1	1,565	1,569	498	255	17	4	820

lowing the appearance of wilt. Nearly half (45.9 percent) of the elms affected by phloem necrosis continued to live during the remainder of the summer in which wilt symptoms appeared but were dead by June of the next summer.

Of the 3,908 Dutch elm disease-affected elms, 3,134 (80.2 percent) died in the year when wilt symptoms appeared. Only 753 (19.3 percent) died during the second year, and 21 (0.5 percent) died during the third summer. These data indicate that, following the initial appearance of foliage wilt, elms having Dutch elm disease die more rapidly than do elms affected by phloem necrosis.

Also of interest are the 820 elms that did not show foliage wilt in the September survey but died before the June survey of the following year. These elms represent 16.5 percent of the 4,959 elms that died during the 6-year period. Although the cause of death was not determined, probably most, if not all, of these elms were killed by Dutch elm disease, since this disease usually causes elms to die more rapidly than does phloem necrosis.

## DISCUSSION

Phloem necrosis was not known to occur in any areas close to Champaign-Urbana when the disease was discovered in two adjacent elms in Urbana in 1944. The nearest area where the disease had occurred was Danville, Illinois, 32 miles [51 km] east of Urbana. Beginning in 1935, elm plantings between Urbana and Danville had been observed for disease symptoms frequently during the growing season of each year.

In the course of this study careful examination of phloem samples from wilting elms showed that the characteristic butterscotch color usually was present only in the current phloem. However, samples from some wilting elms had butterscotch color in 1- and sometimes 2-year-old phloem. This condition occurred mainly in elms that

showed foliage symptoms during two or more growing seasons. Since the butterscotch color in the current phloem indicates that the tree has been infected for about 1 year (Baker 1949:730), the butterscotch color in 1- and 2-year-old phloem indicates that the MLO is in some elms for 2-3 years before foliage wilt appears.

Because phloem necrosis was present in the Champaign-Urbana area 7 years (1944-1950) before Dutch elm disease appeared there, the initial spread of phloem necrosis was not influenced by Dutch elm disease. In Urbana, phloem necrosis spread slowly for 4 years following its appearance in 1944. The few affected trees were widely scattered at distances of approximately 300-2,000 feet [100-600 m] from the two elms first attacked. Each affected tree represented a new center of infection from which the disease continued to spread to nearby elms. This initial spread resulted from transmission of the MLO by the elm leafhopper.

The incidence of phloem necrosis increased rapidly in Urbana during 1948 and 1949, and by 1950 over 300 trees were affected. The disease was concentrated mainly within an area approximately 1,400 feet [400 m] wide and 4,000 feet [1,200 m] long in the central part of the city, an area heavily populated with American elms. By 1950 only a few scattered elms were affected beyond this area, and no affected trees were in the 3,600-foot-wide [1,100 m] area adjacent to Champaign.

In Champaign phloem necrosis was not found until 1948, when it affected four elms. The trees were approximately 5,000 feet [1,500 m] west of any affected trees in Urbana. Following 1948 the number of elms affected by phloem necrosis increased rapidly in Champaign, and all but a few of the affected trees were concentrated in an area two blocks wide and four blocks long, centering around the 700 block of South Lynn Street.

Of the 36 elms in the 700 block of South Lynn Street, 8 wilted in 1949.



The infection of these eight elms resulted from insect transmission of the MLO in 1948 or earlier. Because 28 of the elms in this block wilted in the 2 years following the initial appearance of the disease, it is possible that the MLO was spread by the elm leafhopper. However, all but three of these elms were within root-grafting distance of previously affected trees. Following 1950 phloem necrosis spread rapidly throughout both cities, and the greatest loss of trees from this disease in any 1 year occurred in 1952, 8 years after the disease first appeared.

Phloem necrosis was widespread when Dutch elm disease was discovered in one elm in southwest Urbana in 1951. The infection of this elm resulted from insect transmission of the fungus. However, phloem necrosis-affected elms may have harbored the inoculum, because the Dutch elm disease fungus was isolated from 8 of 40 elms that had phloem necrosis in 1952 (Campana 1954:358). Therefore, many of the hundreds of elms killed annually by phloem necrosis but not removed promptly served as colonizing sites for the smaller European elm bark beetle, vector of the Dutch elm disease fungus. Millions of these insects were present in the Champaign-Urbana area as potential carriers of the Dutch elm disease fungus at the time the disease first appeared.

Following the appearance of Dutch elm disease in 1951, the fungus was transmitted by insects in 1952 and 1953, for only 1 of 175 diseased elms was within root-grafting distance of a previously diseased tree. Although only a few elms were affected in 1952, Dutch elm disease spread rapidly in the next 3 years, and a 5-year peak period of elm deaths started in 1955. Dutch elm disease increased annually more rapidly than did phloem necrosis in the number of elms affected and in the number of infection centers. As the incidence of Dutch elm disease increased, the incidence of phloem necrosis decreased,

and phloem necrosis failed to spread along some streets.

During the peak years of loss from each disease, Dutch elm disease killed approximately four to five times as many elms as did phloem necrosis. The peak of elm deaths from Dutch elm disease occurred over 5 years, while the peak of elm deaths from phloem necrosis occurred in two periods, the first lasting 4 years and the second 2 years. Following these peak periods the numbers of elms affected annually by each disease decreased rapidly, for over 90 percent of the 1944 elm population of Champaign-Urbana had been killed by 1960.

In some blocks and along some streets all elms were killed within 3-5 years by one or both diseases. All 36 elms in the 700 block of South Lynn Street in Champaign were killed by phloem necrosis in 3 years, and 28 of 29 elms in the 700 block of West Michigan Avenue in Urbana were killed by Dutch elm disease in 5 years.

Where both diseases were present, Dutch elm disease killed more trees than did phloem necrosis. Dutch elm disease tends to kill trees more rapidly than does phloem necrosis. Most elms affected by Dutch elm disease die in the same year in which foliage wilt appears, but most elms affected by phloem necrosis die in the year following the appearance of foliage wilt. Also, more phloem necrosis-affected elms show wilt symptoms in September than show them in June, while more Dutch elm disease-affected trees show wilt symptoms in June than show them in September. Some elms die during the winter without any visible foliage wilt. While each disease may contribute to these winter deaths, it seems likely that Dutch elm disease is mainly responsible.

Some elms that first showed symptoms of phloem necrosis subsequently showed symptoms of Dutch elm disease. As the number of elms killed by Dutch elm disease increased, the num-



her of phloem necrosis-affected elms subsequently affected by Dutch elm disease increased. This fact suggests that as the supply of Dutch elm disease inoculum increases, more phloem necrosis-affected elms are invaded by the Dutch elm disease fungus. Also, the greater the number of elms infested with bark beetles, the greater the chances for the spread of the Dutch elm disease fungus.

Although some elms affected by phloem necrosis in June showed Dutch elm disease symptoms in September, in most cases Dutch elm disease symptoms did not appear until the year following the appearance of phloem necrosis symptoms. Only phloem necrosis-affected elms that die slowly during one or more growing seasons can be subsequently affected by and show symptoms of Dutch elm disease. Phloem necrosis-affected elms that are subsequently affected by Dutch elm disease appear to be killed by Dutch elm disease and not by phloem necrosis (Campana & Carter 1955).

The cycle of elm deaths from Dutch elm disease probably was affected only slightly, if at all, by the presence of phloem necrosis. This conclusion is based on the fact that elm deaths from Dutch elm disease built up to a peak more rapidly than did elm deaths from phloem necrosis. During the 5-year period 1955-1959 more than eight times as many elms were killed by Dutch elm disease as were killed by phloem necrosis. However, the cycle of elm deaths from phloem necrosis was greatly shortened by the presence of Dutch elm disease; Dutch elm disease killed 78.4 percent of the elms, while phloem necrosis killed only 21.2 percent.

## SUMMARY

In the 29-year study reported here, data were recorded on the spread of and losses caused by elm phloem necrosis and Dutch elm disease in a mu-

nicipal area which had no community-wide control program for either disease.

Phloem necrosis appeared in Urbana in 1944, when two trees were affected. Dutch elm disease did not appear until 1951, when one tree was affected. The initial spread of phloem necrosis was not influenced by Dutch elm disease, since Dutch elm disease was not present during that period. Each of the 14 elms that contracted phloem necrosis from 1945 through 1948 was scattered at random beyond root-grafting distance of other diseased trees, and each tree represented a separate infection center. Phloem necrosis spread rapidly along some streets, killing all 36 elms in one block within 3 years.

The early spread of Dutch elm disease was influenced by phloem necrosis. Phloem necrosis-affected elms can harbor the Dutch elm disease fungus, and the elms killed by phloem necrosis were heavily colonized by the smaller European elm bark beetle, vector of the Dutch elm disease fungus. Many of the phloem necrosis-affected elms were not removed before the bark beetles emerged.

Dutch elm disease spread rapidly to elms in areas where phloem necrosis was abundant, and it also affected scattered elms located well away from phloem necrosis-affected elms. However, of 164 elms having Dutch elm disease in 1953 only 41 were in scattered locations away from phloem necrosis-affected trees.

Dutch elm disease, like phloem necrosis, spread rapidly to elms along some streets. Twenty-eight elms were killed by this disease in one block in 5 years. Of 47 elms in six blocks of one street, 17 were killed by phloem necrosis in 2 years and 30 were killed by Dutch elm disease in 5 years. However, Dutch elm disease was present for 2 years before phloem necrosis appeared. Phloem necrosis and Dutch elm disease were spread mainly by their respective insect vectors in this area, because 39 of the 47 elms were beyond root-

grafting distance of previously diseased trees.

Some phloem necrosis-affected elms subsequently became infected with the Dutch elm disease fungus and showed typical symptoms of Dutch elm disease before dying. The number of phloem necrosis-affected elms that subsequently became affected by Dutch elm disease increased as the incidence of Dutch elm disease increased.

The greatest number of elms affected by phloem necrosis in 1 year was 555 trees in 1952, 8 years after the disease was discovered in this area. The greatest number of elms affected by Dutch elm disease was 2,116 trees in 1957, 6 years after the disease was discovered here. Of the original population of 14,103 elms, 2,994, or 21.23 percent, were killed by phloem necrosis in 29 years. Dutch elm disease killed 11,062,

or 78.44 percent, in 22 years. Both diseases killed 14,056, or 99.67 percent, of the elms. Dutch elm disease had a greater effect on the residual elm population, since it killed more than three times as many elms as did phloem necrosis.

More elms showed symptoms of phloem necrosis in the September survey than showed such symptoms in the June survey. The reverse was true of elms having Dutch elm disease. Following the appearance of wilt symptoms, elms affected by Dutch elm disease tended to die more rapidly than did elms affected by phloem necrosis. Most elms that had Dutch elm disease died in the growing season in which foliage wilt appeared, while most elms that contracted phloem necrosis died in the year following the appearance of foliage wilt.

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# Some Publications of the ILLINOIS NATURAL HISTORY SURVEY

## BULLETIN

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