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NECTRIA CANKER ON BLACK WALNUT IN

SOUTHWEST MICHIGAN

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CARLA SUZANNE THOMAS

has been accepted towards fulfillment
of the requirements for

MASTER OF SCIENCE degree in BOTANY AND PLANT

PATHOLOGY

John H Hart

Major professor

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# NECTRIA CANKER ON BLACK WALNUT IN SOUTHWEST MICHIGAN

By

Carla Suzanne Thomas

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# ABSTRACT

## NECTRIA CANKER ON BLACK WALNUT IN SOUTHWEST MICHIGAN

BY

Carla Suzanne Thomas

Nectria canker, caused by *Nectria galligena*, Bres. is especially severe on black walnut (*Juglans nigra* L.) in some stands in southwest Michigan. A survey was conducted which indicated several centers of severe disease. Of the 189 survey observations, nectria canker was more likely to be severe on black walnut associated with wetlands, kettles or depressions than on black walnut growing on uplands. When characterized for 30 survey sites, soil type was not related to disease levels, but surface geology and topography were. A severely infected plantation of 2718 black walnut indicated that number of cankers per tree was not correlated with dbh or canker shape. The number of infections increased from 1961 to 1979 with peak years 1978-1980. Most stem sections were 19 to 27 years old, with peaks at 22 and 24. Growth rates varied between trees and within trees, but were similar for cankered and uncankered trees.

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# INTRODUCTION

Nectria canker of hardwoods was reported in Europe as early as 1865 (Hartig, 1880). The first report of the disease in North America was in 1896 when nectria canker was reported as occurring on "a variety of deciduous hosts" (Galloway and Woods, 1896). Over the next 50 years, this disease was reported on many deciduous trees, including species of oak, birch, maple, beech, hickory, walnut, aspen, cherry and apple. During this time, a controversy about Nectria species taxonomy developed which centered on fungal morphology and host range. Taxonomy and host range have been discussed by others (Ashcroft, 1934; Cayley, 1921; Graves, 1919; Lohman and Watson, 1943; Lortie, 1969; Spaulding, Grant and Ayers, 1936). The causal organism of most perennial, target-type nectria cankers on deciduous trees is referred to as Nectria galligena, Bres. However, there may be strains of the fungus which infect some hosts but not others. Isolates from cankers on apple are pathogenic on pear but not on most forest tree species. For this reason, studies concerning nectria canker of apple will not be discussed in length in this study; they are, however, discussed elsewhere (Dubin and English, 1975 a, b; Ng and Roberts, 1974; Zeller, 1926).

Black walnut, Juglans nigra L., is one of our most valuable and beautiful native trees. The heavy, strong, durable heartwood is easily worked and is in great demand. The bark has been used in tanning and a yellow-brown dye can be made from the nut husks. Nuts are eaten by man and many species of wildlife. Nut shells are used by industry in making abrasives.

Only one study has been published concerning nectria canker on black walnut (Ashcroft, 1934) even though N. galligena is reported as a serious pathogen of black walnut in many states, including West Virginia, North Carolina, Georgia, Tennessee (Gravatt, 1933), Michigan, Pennsylvania (this study), Wisconsin, Ontario and Rhode Island (Ashcroft, 1934).

A number of black walnut stands in a four-county area of southwest Michigan have been severely damaged by nectria canker. Although an occasional nectria canker on black walnut is fairly common, the situation in southwest Michigan may be unique in several aspects. In some stands almost every tree is affected, usually with more than one canker.

Nectria canker significantly restricts the growth rate of infected black walnut trees (Brandt, 1964), destroying the veneer value of infected trees. Decay fungi and boring insects may invade diseased tissues (Gravatt, 1933). Because of the premium prices black walnut wood commands, this disease represents a significant loss to some landowners in southwest Michigan. The large callus layers produced by the black walnut tree in response to N. galligena create a grotesque distorted appearance which destroys the ornamental value of black walnut (Figure 1).

The mode of infection also may be unique to this region. The Nectria fungus can only attack a tree through a wound, usually wounds associated with a branch crotch or branch stub (Grant and Spaulding, 1939; Keinholz and Bidwell, 1938; Lortie 1969). This may not be true in southwest Michigan, as new cankers are forming on the trunks of mature

Figure 1. Open cankers on black walnut trunk in southwest Michigan cause disfiguration.

trees where no obvious injury has occurred. Others report that nectria canker occurs on young hardwoods two to 20 years old (Brandt, 1964; Kress and Wood, 1974; Merrill and Finley, 1981). Yet in Michigan, 100-year-old trees have new cankers at various heights along the trunk.

Preliminary field observations indicate that the disease has been persistent in this localized area for a period of years and does not seem to be spreading to adjacent areas. Nectria canker of hardwoods is commonly thought to be associated with less vigorous trees growing on shallow, poorly drained, infertile soils (Ashcroft, 1934; Brandt, 1964; Keinholz and Bidwell, 1938). Sites in regions of frequent snow and ice storms or at high elevations also may have severe nectria canker problems (Ashcroft, 1934; Brandt, 1964; Grant and Childs, 1940; Roth and Hepting, 1954). Nectria canker of yellow birch was severe when trees were within five miles of Lake Michigan or Lake Superior in Michigan's upper peninsula (Anderson and Mosher, 1979). Although Ashcroft did a brief survey by county of nectria canker on black walnut in West Virginia, his work was primarily concerned with fungal taxonomy, host range and histopathology of the disease, not epidemiology and site factors.

The purposes of this study were to determine 1) the precise geographic extent of nectria canker severity on black walnut in southwest Michigan and quantify the association of site factors with disease to explain why disease is serious only in a localized area, 2) the wound type, if any, associated with cankers and 3) the ages of trunk sections and chronological years of highest infection levels, 4) the impact of nectria canker on growth of black walnut.

# MATERIALS AND METHODS

## Survey

To determine where nectria canker is severe on black walnut, a survey was conducted in five counties in southwest Michigan during 1983 and 1984. Transects were established at three mile intervals from north to south and from east to west for Berrien, Cass, St. Joseph, Kalamazoo and Van Buren Counties. The survey was started at Russ Forest, a known area of severe disease and was continued outward in all directions until a one township wide border consisting of normal levels of disease (<6% stand infection) surrounded the surveyed area. Each stand, 10 or more black walnuts closest to each intersection of north-south and east-west grid lines was identified by county, township, section, quarter section and stand number (in case of more than one observation per quarter section) and the location recorded on township platt maps. The number of acres in the stand, tree stage (pole = <14 inches dbh, mature = >14 inches dbh), site wetness (wet or drained) and origin (roadside, forest or plantation trees) also was recorded. Distribution (local, spotty or general) was recorded for open, closed and combined cankers at each site. Cankers were open if three or more callus layers were seen. Cankers were closed if only one or two callus layers were seen. Then the percent infection per stand and the average percent of a trunk covered by cankers were recorded for open and closed nectria cankers according to the scale 1 = no infection, 2 = 1 to 5 percent, 3 = 6 to 20 percent, 4 = 21 to 50 percent and 5 = greater than 50. Percent infection for open and closed cankers combined (total cankers) was recorded for individual trees and for the stand according to the scale 0

= no infection, 1 = 1 to 5 percent, 2 = 6 to 15 percent, 3 = 16 to 25 percent, 4 = 26 to 50 percent, 5 = 51 to 75 percent and 6 = greater than 75 percent. Two scales were used in order to facilitate the coding system of the Michigan State University Cooperative Crop Monitoring Service that was used to code the preceding variables. Basal area (square feet per acre) was recorded for each site.

To determine the variability within a more local area, Volinia township in Cass County, was surveyed intensively during 1983. The survey was conducted by driving all roads in the township and recording the information mentioned above for all black walnut stands located. Occasional yard trees or roadside trees were ignored unless there were more than five at a site. All woodlots were surveyed on foot if black walnut was observed growing at the edge of the stand.

Elevation above sea level and approximate depth to the water table were recorded from quadrangle topographic maps for each site. Surface geology of each site was determined using quadrangle maps stored at the Michigan Geological Survey, Lansing, from H. Martin's study (1955). An attempt to record soil types from maps was abandoned since Cass County has not been surveyed using currently accepted methods and maps would not have given suitable information.

### Soils and Topography

During July 1984, soil profiles, surface geology, aspect, estimated percent slope, drainage class and parent material were recorded at 30 of the survey sites. Topography was diagrammed. Ten of these sites were locations where disease was severe (stands with greater than 75 percent infection). These encompassed all of the forest sites where land owners were cooperative and disease was severe. Ten sites were randomly selected where normal levels of disease (0-5 percent infection) occurred on flat microrelief. Ten sites were randomly selected where normal levels of disease occurred on rolling microrelief. In no cases did trees on steep microrelief have less than 6 percent infection. Microrelief was determined from quadrangle topographic maps.

Soils were characterized by horizon, depth, structure, consistency, texture and the presence of gravel, boulders, clay skins, mottles and other distinguishing features. Depth to water table was recorded when possible. In each case, the surface soil layers were sampled by digging a pit approximately 0.5 meters deep. Subsoil and parent material were sampled to a depth of up to 4.5 meters using a three inch bucket agar. In some cases, subsurface horizons could not be penetrated with a bucket agar due to massive structure or a high density of large cobbles and boulders.

Several sites south of State College in Huntington County, Pennsylvania, where nectria canker is severe on black walnut, were visited to compare disease severity and topography with black walnut in Michigan.

Effect of Tree Vigor and Competition in a Russ Forest Plantation

The incidence of nectria canker on black walnut was mapped in a mixed hardwood plantation which was established at Russ Forest in 1945 and 1946. The stand consisted of black walnut planted every fourth row in an east-west direction, with red oak, tulip poplar or ash and black cherry rows planted between the black walnut rows. In every case, black cherry was in the row to the south and red oak or ash was in the row to the north. Clearings were established in spring 1981. These resulted in seven rows of black walnut that had clearings to the north and six rows of black walnut that had clearings to the south. Row number (1-65), dbh (1-15.5 inches, mean = 6.0 ± 2.3) and number of cankers between 1 ft and 12 ft above ground on the trunk (0-51, mean = 1.3 ± 3.8) were recorded for all 2,718 black walnuts in the stand. Whether the cankers were open (0 = none or no, 1 = yes), closed (0 = none or no, 1 = yes) or if a tree had an adjacent clearing to the north (0 = none or no, 1 = yes) or to the south (0 = none or no, 1 = yes) also was recorded for each tree. Presence of clearings, canker shape and number, tree dbh and distance to the creek (row number) were used as independent variables in multiple linear stepwise addition regressions with canker number as the dependent variable. The STAT 4 statistical package was used in the analysis.

The soil variability of the stand was investigated by characterizing the soil in the same manner as for the survey sites. The soil was sampled at 11 pits established between every third and fourth black walnut row in the north two-thirds of the stand. Each pit was dug halfway between two rows of black walnut. The mean number of cankers per tree was calculated for each pit location using the values of the 10 closest trees in each of the two adjacent rows.

Canker Dissections

Eleven black walnut, 6 inches dbh or larger with 400 ft of each other, from the Russ Forest Plantation were cut in 1984. Seven of the trees were infected with nectria canker. Two of the infected trees were used in the isolation studies. Two hundred cankers were dissected from random logs (Table 1). Cuts were made radially into cross-sections.

Table 1

Summary of nectria canker data for 40 year old black walnut trees collected 1984 from Russ Forest Plantation D46. Tree diameters, number of cankers per tree and predominant canker shape are included.

| Tree no.[a] | Diameter at breast height (inches)[b] | No. of externally apparent cankers[b] | Predominant canker shape[b] | No. of Cankers dissected[d] |
|---|---|---|---|---|
| 1 | 7.9 | 8 | closed | 13[c] |
| 2 | 8.3 | 13 | open | 14[c] |
| 3 | 6.0 | 8 | open | 24 |
| 4 | 8.8 | 11 | closed | 13 |
| 5 | 8.8 | 21 | closed | 60 |
| 6 | 8.9 | 7 | open | 30[c] |
| 7 | 7.2 | 9 | closed | 46[c] |
| mean | 8.0 | 11 | - | 29 |

[a]Trees 1 and 2 also were used for fungal isolation studies.

[b]From field observations October, 1983.

[c]Not all cankers from each tree were dissected.

[d]The number of cankers dissected is greater than the number of externally apparent cankers due to the presence of closing cankers which were not detected from the outside of the tree.

To determine the tree growth reduction due to nectria canker, the number of tree rings in the inner 0.4 inch of the cross-section were recorded for the widest and narrowest directions, since infected stems were often asymmetric. Similar measurements were recorded for tree rings in the outer 0.4 inch. The values were used to obtain a mean growth rate before (inner) and after (outer) infection. The four infected trees were used as controls. A mean growth rate for the inner and outer 0.4 inch was obtained from the top (20-25 years old), middle (26-30 years old) and bottom (31-34 years old) of the trunk of each tree. Percent growth reduction was calculated as

$$\left[1 - \frac{\text{mean no. rings/0.4 inch, inner}}{\text{mean no. rings/0.4 inch, outer}}\right] \times 100 = \%\ \text{gr. red.}$$

Percent growth reduction for the top, middle, and bottom sections of non-cankered trees was compared to percent growth reduction for top, middle and bottom sections of cankered trees.

To determine the age of the stem section at the time of infection, the number of rings from the pith to the first infected ring was recorded. To determine the year of infection, the number of rings from the bark to the first infected ring was determined. The type of wound and whether the canker was open or closed was recorded as well. No distinction between living branch and branch stub was made. If boring insects were secondary to infection, this was noted.

To verify the identity of the causal organism and to determine the location of infected tissues within the tree, two trees were harvested from the Russ Forest plantation. One tree had predominantly closed cankers and one had predominantly open cankers (Table 1). The trunks were cut into five foot lengths, transported to Michigan State University, where the cankers were dissected by cutting radially into 1.5 cm cross sections. These sections were photographed. Isolations were made from discolored and normal sapwood and heartwood of six closed and four open cankers by aseptically removing wood chips and placing them on Difco potato dextrose agar (PDA). Hyphal tips were removed and subcultured on PDA and incubated at 65-72$^{o}$ F under diffuse daylight. Colonies with similar morphology were grouped and identified.

After Cylindrocarpon heteronema (Berk. and Br.) Wollenw., the imperfect stage of N. galligena, was identified in pure culture, several media were tested for optimal growth and sporulation. The media used were Difco oatmeal agar, 2 percent water agar, Difco potato dextrose agar, V-8 agar, autoclaved Quaker oats added to sterile water or to 2 percent water agar, Quaker oats autoclaved with water, and autoclaved black walnut twigs placed in sterile, melted 2 percent water agar. Another medium treatment consisted of sterile Quaker oats on top of 2 percent water agar. C. heteronema was inoculated on April 24, 1984 and plates were observed weekly until September for growth and sporulation.

## RESULTS

### Survey

The regional survey contained data for 149 sites. Forty additional sites were located in the Volinia Township survey, resulting in 189 observations in all (Figure 2). Table 2 summarizes the variables used in multiple linear stepwise addition regressions of the factors recorded. The STAT 4 statistical package was used for the analyses.

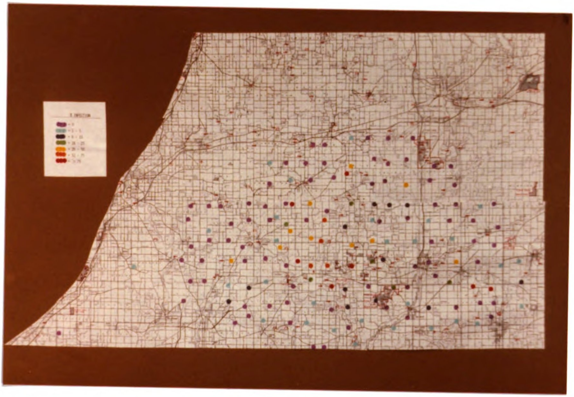


Figure 2. A) Locations of survey sites for nectria canker on black walnut in southwest Michigan. Each dot represents one stand of black walnut. Dots are color-coded for % black walnut trees infected: purple = none, light blue = 1-5, dark blue = 6-15, green = 16-25, yellow = 26-50, orange = 51-75, red = >75.

Table 2

Summary of the variables used in the survey of nectria canker on black walnut in southwest Michigan.

| Independent variable | Levels or codes | Independent variable mean | Standard deviation | Frequency of occurrence |
|---|---|---|---|---|
| Stand Stage Code | 0 = mature (>14 inches dbh) | | | 44 |
| | 1 = pole (<14 inches dbh) | | | 145 |
| Site Wetness Code[a] | 0 = drained | | | 151 |
| | 1 = wet | | | 38 |
| Origin Code | 0 = roadside | | | 85 |
| | 1 = forest or plantation | | | 104 |
| Basal Area (sq ft/acre) | 10-140 | 39.45 | 20.60 | |
| Elevation (ft above sea level) | 610-1030 | 851.61 | 62.39 | |
| Depth to Water Table (ft) | 10-140 | 26.73 | 24.09 | |

[a]Soils were considered to be wet if there was standing or slowly moving water, at least 1 acre in size, within 200 meters of site and at the same elevation ( ± 10 ft.). Otherwise, soils were drained.

The results of these regressions are summarized in Table 3. All equations were highly significant ($P < 0.0005$). Stepwise deletions resulted in the same equations.

The results of the linear stepwise addition regressions indicated that nectria canker was more likely to be severe at sites that were at higher elevations, on wet sites or in mature stands (Table 3). The percent of a tree with closed cankers was larger with larger basal diameter (basal area). This is not surprising since older trees have larger basal areas. In no case did depth to water table or the origin of trees correlate significantly with disease.

The same factors are significant in percent infection resulting in closed cankers, open cankers or total cankers on a per stand or a per tree basis except for basal area code which was only important on a per tree basis for closed cankers. Site wetness, elevation and stage code were important for total cankering per tree and per stand. For this reason and because of a more sensitive scale used for recording percent total cankers, the percent infection of total cankers per stand values were used for succeeding mapping studies. The independent variables listed in Table 3 explain only about 30 percent of the variability in percent infection of nectria canker. Other, unknown factors may influence disease severity, or perhaps elevation, site wetness and stage are not causative factors, but are associated with some factor that has a more direct influence on disease.

While recording elevation values from topographic maps, it was noticed that some of the most severely diseased sites were in very hilly areas (Figure 3). The topography of this area is due to glaciation

Table 3

Summary of multiple linear stepwise addition regressions of site factors from a survey of nectria canker on black walnut in southwest Michigan.

| Dependent Variables (Percent Infection)[a] | Independent Variables Added[b] | Variable No. | $R^2$ | Regression Equation[c] |
|---|---|---|---|---|
| Closed cankers per stand | Elevation<br>Site Wetness Code<br>Stage Code | $X_1$<br>$X_2$<br>$X_3$ | 0.28 | $Y = -3.25 + .01X_1 + .75X_2 - .68X_3$ |
| per tree | Stage Code<br>Elevation<br>Site Wetness Code<br>Basal Area | $X_1$<br>$X_2$<br>$X_3$<br>$X_4$ | 0.28 | $Y = -3.18 - .65X_1 + .01X_2 + .72X_3 + .01X_4$ |
| Open Cankers per stand | Stage Code<br>Site Wetness Code<br>Elevation | $X_1$<br>$X_2$<br>$X_3$ | 0.30 | $Y = -2.32 - .78X_1 + .93X_2 + .01X_3$ |
| per tree | Stage Code<br>Site Wetness Code<br>Elevation | $X_1$<br>$X_2$<br>$X_3$ | 0.29 | $Y = -1.90 - .99X_1 + .81X_2 + .01X_3$ |
| Total Cankers per stand | Site Wetness Code<br>Elevation<br>Stage Code | $X_1$<br>$X_2$<br>$X_3$ | 0.35 | $Y = -6.52 + 1.62X_1 + .01X_2 - 1.12X_3$ |

Table 3 (continued)

| | | | | |
|---|---|---|---|---|
| per tree | Stage Code<br>Elevation<br>Site Wetness Code | $X_1$<br>$X_2$<br>$X_3$ | 0.29 | $Y = -5.86 - 1.36X_1 + .01X_2 + 1.40X_3$ |

[a]Percent infection of closed and open cankers was measured based on the scale 1 = none, 2 = 1-5, 3 = 6-20, 4 = 21-50, and 5 = >50. Percent infection of total cankers was measured based on the scale 0 = none, 1 = 1-5, 2 = 6-15, 3 = 16-25, 4 = 26-50, 5 = 51-75 and 6 = >75.

[b]Independent variables are listed in the order of addition. When origin code, basal area or depth to water table were not listed, they were not significant.

[c]All regression equations are highly significant ($\underline{P} < 0.0005$).

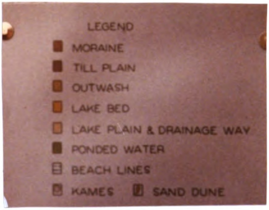
Figure 3. Topographic map of Volinia township survey in Cass County. Brown lines are 20-ft. contour lines. Each dot represents one stand of black walnut. Dots are color-coded for % black walnut trees with nectria canker: purple = none, light blue = 1-5, dark blue = 6-15, green = 16-25, yellow = 26-50, orange = 51-75, red = >75.

during the Wisconsin age of the Pleistocene Epoch. The relationship of disease severity (percent stand infection) to surface geology is shown in Figure 4. Sites with abnormally high levels of disease (greater than 5 percent infection) were more likely to occur on glacial till (till plain or terminal moraine) according to a $x^2$ test (P = 0.05, Appendix Table I). However, not all sites on till have severe disease. This could mean that some factor(s) is involved which is associated with till but is not exclusive to it. Terminal moraines are generally more hilly than till plains followed by outwash, which are more hilly than lacustrine landforms. Soils which develop on till are comprised of a variety of poorly sorted components. In comparison, soils which develop on outwash are well sorted and often sandy. Lacustrine soils are usually fine textured and are clayey or silty.

Soils and Topography

Four types of soils were encountered at the 30 sites investigated. One of the most common is a sandy loam over unaggregated sand. Often there is a hard layer with white flecks in it at the boundary between the sandy loam and sand (Table 4). This soil type often occurred on outwash. Another common soil was a sandy clay loam over sandy clay (Table 5). This soil type often occurred on till plains and moraines. Occasionally a soil was encountered which was clayey and had many large cobbles and boulders, to the extent that it was hard to get the bucket agar through it (Table 6). This soil was probably a subcategory of the clayey type just described, but it was not possible to get the bucket agar deep enough to be certain. The other soil encountered was a sandy loam that extended beyond the depth of the bucket agar (Table 7). This

A




B

Figure 4. Relationship of nectria canker on black walnut to surface geology of Kalamazoo, Van Buren, Cass and St. Joseph Counties in southwest Michigan. Each dot represents one stand of black walnut. Dots are color-coded for % black walnut trees infected: purple = none, light blue = 1-5, dark blue = 6-15, green = 16-25, yellow = 26-50, orange = 51-75, red = >75. Maps are from field notes of H. Martin's study (1955), Michigan Geological Survey. B) Legend of surface geology.

Table 4

Modal description of the sandy soil type.

| | |
|---|---|
| A | 0-10 cm; very dark grayish brown (10 YR 3/2) sandy loam; weak medium granular structure; loose consistency; common medium roots. |
| AB | 10-35 cm; dark brown (10 YR 4/3) sandy clay; weak fine granular structure; loose consistency; common coarse roots. |
| Bt | 35-50 cm; dark yellowish brown (10 YR 4/4) sandy clay; strong coarse angular blocky; hard consistency; 10% gravel. |
| Bx | 50-80 cm; dark yellowish brown (10 YR 4/4) sandy clay loam; strong coarse angular blocky structure; extremely hard consistency; 10% 2-3 mm white gravelly flecks and gravel. |
| C1 | 80-150; dark yellowish brown (10 YR 4/4) sand; structureless single grained; loose consistency; 10% gravel. |
| C2 | 150-400; dark yellowish brown (10 YR 4/6) sand; structureless single grained; loose consistency; 10% gravel; 50% large brownish yellow (10 YR 6/8) mottles; moist. |

Table 5

Modal description of the clayey soil type.

| | |
|---|---|
| A | 0-5 cm; black (10 YR 2/1) sandy clay loam; weak coarse granular structure; soft consistency; many fine roots. |
| E | 5-50 cm; dark grayish brown (10 YR 4/2) sandy loam; moderate coarse subangular blocky structure; soft consistency; common fine to coarse roots; 3% gravel. |
| Bt1 | 50-60 cm; brown (10 YR 5/3) sandy clay loam; moderate coarse subangular blocky structure; soft consistency; 20% gravel. |
| Bt2 | 60-230 cm; dark yellowish brown (10 YR 4/4) sandy clay loam; moderate medium subangular blocky structure; soft consistency; 30% gravel and cobbles. |
| Bt3 | 230-280 cm; yellowish brown (10 YR 5/4) sandy clay loam; moderate medium subangular blocky structure; soft consistency; 30% gravel and cobbles; 30% yellowish brown (10 YR 5/8) medium mottles; moist. |
| C | 280-300 cm; yellowish brown (10 YR 5/4) sandy clay; moderate, massive structure; hard consistency; 30% gravel; 30% yellowish brown (10 YR 5/8) medium mottles; moist. |
| Cg | +300; grayish brown (10 YR 5/2) sandy clay; weak massive structure; soft consistency; 30% cobbles and gravel; saturated. |

Table 6

Modal description of the rocky soil type.

| | |
|---|---|
| A | 0-13 cm; very dark gray (10 YR 3/1) sandy clay loam; weak medium granular structure; soft consistency; common coarse roots. |
| AC | 9-13 cm; very dark gray (10 YR 3/1) sandy clay; weak medium granular structure; soft consistency; 50% gravel and boulders. |
| C1 | 9-23; dark grayish brown (10 YR 4/2) sandy clay; moderate medium subangular blocky structure; extremely hard consistency; 50% gravel and boulders. |
| C2 | 23-63 cm; dark brown (10 YR 4/3) sandy clay; moderate medium subangular blocky structure; hard consistency; 50% gravel. |
| C3 | +63 cm; dark brown (10 YR 4/3) sandy clay; strong massive structure; extremely hard consistency; 50% gravel and cobbles. |

Table 7

Modal description of the loamy soil type.

| | |
|---|---|
| A1 | 0-8 cm; black (10 YR 2/1) sandy loam; weak medium subangular blocky structure; soft consistency; common fine to coarse roots. |
| A2 | 8-30 cm; very dark grayish brown (10 YR 3/2) sandy loam; moderate medium subangular blocky consistency; hard structure; common coarse roots. |
| E | 30-75 cm; brown (10 YR 5/3) sandy loam; structureless fine single grained; loose consistency. |
| Bt | 75-90 cm; dark brown (10 YR 4/3) clay; strong medium subangular blocky structure; hard consistency. |
| CB | 90-135 cm; yellowish brown (10 YR 5/4) loamy sand, medium single grained structure; loose consistency; 30% coarse yellowish brown (10 YR 5/6) mottles. |
| C | 135-150 cm; dark yellowish brown (10 YR 4/4) sand; medium single grained structure; loose consistency; moist. |
| Cg | +150 cm; grayish brown (10 YR 5/2) sandy loam; medium single grained structure; loose consistency; saturated. |

soil often occurred on outwash or in low areas of accumulation within a moraine system. The sandy soil was usually but not always an Oshtemo series. The clayey soil was usually a Riddles series. The rocky and loamy soils were more variable. However, since soil chemistry was not investigated, these classifications are only tentative.

Soil properties and topographic features were compared for the 30 sites. Qualitative variables were analyzed with a $\chi^2$ contingency test. Quantitative variables were analyzed with linear regression. Drainage class, soil type (sandy, clayey, rocky or loamy, see Appendix Table II), soil series (taxonomy), depth of rooting, and depth to gleying, to saturation, to the least permeable layer, and to mottles had no apparent relationship with disease rating. The textures of the least permeable layer, A horizon and B horizon showed no apparent relationship to stand percent infection rating. If the C horizon was gravelly, the site was more likely to have severe disease than if it was sandy ($\underline{P}$ = 0.02, Appendix Table III).

Topographic features were related to disease (Table 8). Sites that were more hilly, as measured by steeper microrelief, greater macrorelief index, higher elevation and greater percent slopes, had black walnut with greater nectria canker incidence (Appendix Tables IV - VIII). Also, if sites were in a low flat area, kettle bottom, or adjacent to wetlands, they were more likely to have black walnut with greater disease levels. Sites were considered to be adjacent to wetlands if they were within 200 m, and at similar elevations (±10 ft), of at least 1 acre of standing or slowly moving water. Generally, disease was not severe unless at least two of these factors were present. Of the stands

Table 8

Relationship of soil and topographic features of 30 black walnut stands in southwest Michigan to nectria canker disease severity.

| | | | | | Microsite | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Stand no. | Disease rating[a] | Macro-relief index[b] | Micro-relief[c] | Presence of wetlands[d] | Topographic Position[e] | Aspect | % slope | Glacial mode of deposition[f] | Elevation above sea level (ft) | Texture of C horizon[g] |
| 18 | 0 | 0.8 | FLAT | - | TF | | 0 | OTWS NP | 805 | S |
| 22 | 0 | 0.8 | FLAT | - | TF | E | 2 | OTWS NP | 870 | S |
| 29 | 0 | 1.8 | FLAT | + | TF | | 0 | OTWS NP | 750 | S |
| 28 | 0 | 2.0 | FLAT | - | TF | S | 4 | OTWS NP | 920 | S |
| 21 | 0 | 3.5 | FLAT | + | LF | N | 2 | OTWS NP | 850 | GSC |
| 14 | 0 | 8.0 | FLAT | - | MS | S | 4 | OTWS P | 845 | S |
| 12 | 0 | 9.3 | FLAT | + | LS | E | 8 | DEPM | 880 | SC |
| 17 | 1 | 2.0 | FLAT | - | TS | N | 8 | TLPL P | 825 | GS |
| 23 | 1 | 3.0 | FLAT | - | TS | E | 8 | OTWS T | 845 | GS |
| 16 | 1 | 3.5 | FLAT | - | LS | E | 8 | KM | 880 | GSL |
| 13 | 1 | 3.8 | ROLL | + | TF | | 7 | TLPL | 900 | S |
| 7 | 1 | 5.3 | ROLL | + | LF | S | 9 | TLPL | 840 | SC |
| 26 | 1 | 5.5 | ROLL | - | MS | S | 7 | OTWS P | 760 | SC |
| 27 | 1 | 5.5 | ROLL | - | MS | S | 9 | OTWS T | 760 | SL |
| 9 | 1 | 7.3 | ROLL | - | LF | | 0 | DEPM | 860 | C |
| 8 | 1 | 8.0 | ROLL | - | US | NW | 8 | TLPL T | 860 | GLS |
| 10 | 1 | 8.5 | ROLL | - | LS | W | 9 | TLPL | 850 | S |
| 11 | 1 | 8.5 | ROLL | - | US | S | 8 | TLPL | 950 | GS |
| 20 | 1 | 11.0 | ROLL | - | US | NW | 5 | OTWS P | 940 | GS |
| 30 | 1 | 11.8 | ROLL | - | TF | N | 4 | TLPL | 880 | |
| 1 | 6 | 2.0 | FLAT | + | LF | | 0 | OTWS NP | 860 | GS |
| 4 | 6 | 3.0 | FLAT | + | LF | | 0 | OTWS NP | 850 | GS |

Table 8 (continued)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 6 | 3.0 | FLAT | + | LF | N | 1 | OTWS | NP | 870 | S |
| 19 | 6 | 6.5 | STEEP | + | LF | W | 9 | OTWS | KL | 880 | GSC |
| 15 | 6 | 8.5 | STEEP | + | MS | E | 10 | STMR | KL | 870 | GS |
| 5 | 6 | 8.8 | STEEP | - | MS | N | 2 | TLPL | | 960 | |
| 24 | 6 | 10.3 | STEEP | + | LS | N | 4 | STMR | KL | 860 | SIC |
| 2 | 6 | 12.5 | STEEP | - | US | W | 8 | STMR | | 1030 | GSC |
| 6 | 6 | 12.8 | STEEP | - | MS | NE | 20 | OTWS | KL | 940 | GS |
| 25 | 6 | 18.0 | STEEP | - | LF | | 12 | OTWS | KL | 880 | SC |
| $p^h$ = | | 0.04 | 0.0005 | 0.08 | 0.06 | 0.34 | 0.37 | 0.02 | | 0.04 | 0.02 |
| $\bar{R}^2$ = | | 0.15 | | | | | 0.03 | | | 0.15 | |

[a]Disease rating was based on percent infection of nectria canker on black walnut in the stand: 0 = none, 1 = 1-5%, 2 = 6-15%, 3 = 16-25%, 4 = 26-50%, 5 = 51-75% and 6 = >75%.

[b]Relief index was calculated as the average of 4 values obtained by counting the number of 20 ft contour lines encountered along 1.2 mi. grid lines drawn from the stand to the north, east, south and west.

[c]Sites were chosen on the basis of 10 apparently flat with low disease, 10 apparently rolling with low disease and 10 with high disease levels.

[d]Locations were considered to have wetlands present if they were within 200 m. of at least one acre of standing or slowly moving water and at similar elevations (±10 ft.) to that water.

[e]TF = top flat, US = upper slope, MS = middle slope, LS = lower slope, LF = low flat.

Table 8 (continued)

[f]OTWS = outwash, DEPM = moraine associated deposition of eroded material, TLPL = till plain, STMR = Sturgis Terminal Moraine, P = pitted, NP = not pitted, T = top bank of creek, KL = kettle, KM = Kame.

[g]S = sand(y), G = gravelly, C = clay.

[h]Qualitative variables were analyzed by $x^2$ contingency tests (see Appendix for contingency tables). Quantitative variables were analyzed by linear regression. Disease rating was the dependent variable for all analyses.

that had disease ratings of 6 (>75 percent infection), none were on south slopes or on high flat positions. Of the 30 sites studied intensively, all of the stands which were in kettles or on moraine material had severe disease levels (>75 percent infection).

North slopes, depressions and wetlands are places where cool air accumulates(cold pockets). To verify these trends, field notes and topographic quadrangle maps were used to determine if the site was located in uplands, wetlands, kettles or depressions for 189 survey sites in the five county area (Table 9). A site was considered to be an upland site if it was not a kettle, a depression or adjacent to a wetland. A stand was much more likely to have abnormally high disease levels (>5 percent infection) if it was adjacent to a wetland, in a kettle or a depression ($\underline{P} < 0.0005$), according to a $\chi^2$ contingency test. However, not all wetlands, kettles and depressions had abnormally high levels of disease. Not all uplands had low levels of disease. Therefore, other unknown factors in conjunction with cold pockets may result in high levels of nectria canker on black walnut.

Black walnut growing in central Pennsylvania was observed in the valley south of Tussey Mountain. This area included portions of Rothrock State Forest and Pennsylvania State University Experimental Forest near Masseyburg. The valley sloped downhill to the southwest between two large ridges. There are several smaller ridges in the center of the valley. Black walnut was abundant in the valley but not on the ridge tops. More than half of the trees observed had nectria cankers. In some places, every black walnut tree had multiple stem and branch cankers. Both open and closed cankers were observed. Perithecia

Table 9

Summary of the relationship between topography and stand percent infection rating of 189 nectria canker survey sites for black walnut in southwest Michigan. Topography is significantly related to percent infection according to a $X^2$ contingency test ($P < 0.0005$).

| Stand percent infection | Uplands | Wetlands | Kettles | Depressions |
|---|---|---|---|---|
| | Number sites observed | | | |
| 0 | 86 | 4 | 0 | 4 |
| 1-5 | 21 | 7 | 1 | 8 |
| 6-15 | 2 | 4 | 1 | 6 |
| 16-25 | 0 | 4 | 1 | 5 |
| 26-50 | 1 | 5 | 0 | 6 |
| 51-75 | 0 | 5 | 0 | 5 |
| >75 | 1 | 6 | 5 | 1 |
| Subtotal | 111 | 35 | 8 | 35 |
| TOTAL = 189 | | | | |

were present on the callus layers of some open cankers. The soils appeared to be very clayey with many coarse, shaley fragments present. Elevations ranged from 1,000 to 2,000 feet above sea level for valley bottoms and ridge tops, respectively. At another site 40 miles to the northeast, several black walnut trees were observed in a valley named Porter Run. These trees also had multiple nectria cankers and were in a valley.

Effect of Tree Vigor and Competition in a Russ Forest Plantation

The results of the individual tree measurements are summarized in Table 10. When all 2,718 tree observations were used, diameter and presence of open and closed cankers were positively correlated with disease ($R^2$ = 0.40). However, this is an artifact of the dumby variable system used, since 0 cankers results in a rating of 0 for open and for closed cankers. To eliminate this complication, a second regression was done using only infected trees. This also eliminates any genetically resistant or escape trees. As Table 10 illustrates, dbh and canker shape (open and closed) were positively correlated to canker number and significant ($P$ < 0.0005), but explained a small portion of variability when only infected trees were used ($R^2$ = 0.06).

Whether or not the trees had adjacent clearings to the north or south and the trees' distance to the creek as measured by row number were not significant in any of the regressions on canker number. Since most of the clearings were initiated recently (1981), perhaps the duration of the clearing treatment had not been long enough.

The soil was characterized for 11 locations within the stand in the same manner as for the survey sites. No apparent differences were

Table 10

Summary of multiple linear regressions of row number, diameter breast height, clearing, canker number and canker shape of individual black walnut trees in a plantation in southwest Michigan.

| Dependent Variable | Independent Variable(s)[a] | Variable No. | $R^2$ | Regression Equation[b] |
|---|---|---|---|---|
| Cankers per tree (all observations used) | Closed cankers<br>Open cankers<br>DBH | $X_1$<br>$X_2$<br>$X_3$ | 0.40 | $Y = -0.70 + 5.27X_1 + 6.44X_2 + 0.12X_3$ |
| Cankers per tree (infected trees only) | DBH<br>Closed cankers | $X_1$<br>$X_2$ | 0.05 | $Y = 2.51 + 0.65X_1 - 1.70X_2$ |

[a]Independent variables are listed in the order of addition. When the independent variables distance to creek (row number), clearing to the north, clearing to the south, open cankers or closed cankers are not listed, they were not significant ($P = 0.10$).

[b]Stepwise deletion and addition resulted in the same equation. All regressions were highly significant ($P < 0.0005$).

found in depth of rooting, depth to water table, depth to mottles and soil classification in relation to mean number of cankers per tree.

Canker Dissections

There is a two- to four-fold difference in actual canker number compared to apparent canker number (Table 1). This is partly due to poor visibility of higher portions of the tree, but mainly due to difficult-to-see closed cankers which were present on infected trees.

All cankers were initiated after 1960, with peak years of infection 1978 to 1980 (Figure 5). As summarized in Figure 6, there was a higher frequency of infection for black walnut stem sections 19 to 27 years old, with peaks at 22 and 24 years old. Thirty-one percent of the cankers were associated with branch stubs and 0.5 percent with a wound from a boring insect. There was no apparent wound associated with infection for 68.5 percent of the cankers. Secondary flat-headed borers and ants were apparent in 3.5 and 1.0 percent of the cankers, respectively. They were usually associated with open cankers. Such insects could be responsible for creating wounds which would not be readily apparent.

Trees infected with nectria grew more slowly after infection than before infection (Table 11). However, uninfected trees also exhibited a reduction in growth. The growth reduction for the bottom and top portions was greater in infected black walnut than in uninfected black walnut. Yet growth reduction in the middle portion was similar for infected and noninfected trees. Ranges in growth reduction for healthy and diseased trees overlap, indicating that nectria canker may not significantly reduce growth rates of black walnut. However, there are

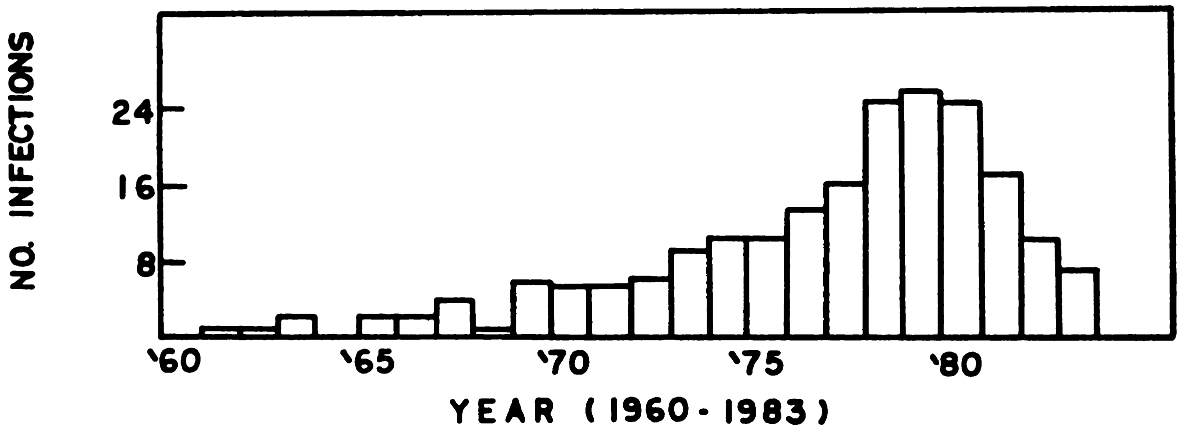



Figure 5. Frequency of infection for 200 nectria cankers from 7 black walnut trees collected at Russ Forest Plantation D46. No cankers were initiated before 1961.

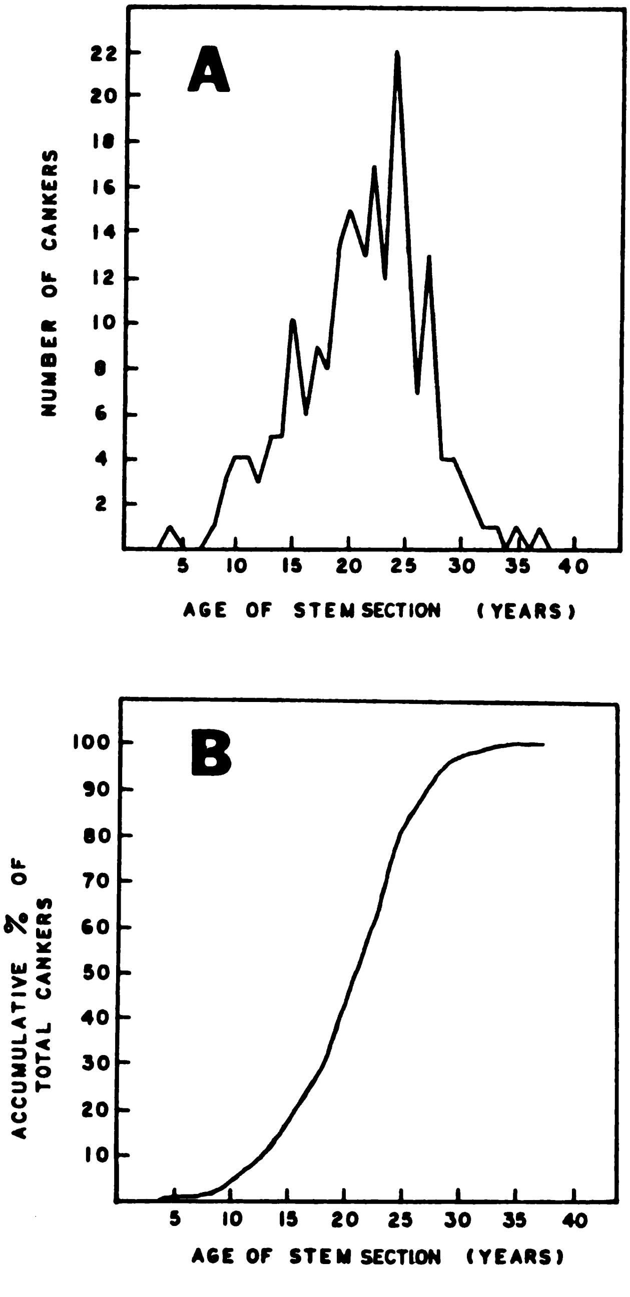



Figure 6. Relationship between age of black walnut stem tissue and A) frequency of nectria canker infection B) accumulative percent of total nectria canker infection for 200 trees.

Table 11

Percent growth reduction in top, middle and bottom portions of infected and uninfected black walnut.

| Tree No. | Nectria canker | Top (20-25 yrs. old) | Middle (26-30 yrs. old) | Bottom (31-34 yrs. old) | Tree Mean |
|---|---|---|---|---|---|
| 1 | + | 56.28[a](10) | 44.33(2) | NA[b] | 50.31 |
| 2 | + | NA | 37.77(5) | 38.67(5) | 38.22 |
| 3 | + | NA | 61.93(6) | 63.29(7) | 62.61 |
| 4 | + | NA | 53.85(5) | 47.67(4) | 50.76 |
| 5 | + | 53.81(9) | 49.40(31) | 48.16(12) | 50.46 |
| 6 | + | 50.00(5) | 41.01(11) | 41.90(6) | 44.30 |
| 7 | + | 57.34(5) | 56.42(7) | 57.90(7) | 57.22 |
| 8 | - | 20.00 | 28.57 | 28.57 | 25.71 |
| 9 | - | 45.46 | 58.33 | 36.37 | 46.72 |
| 10 | - | 44.44 | 40.00 | 0.00 | 28.15 |
| 11 | - | 40.00 | 66.67 | 25.00 | 43.89 |
| Mean infected trees | | 54.36 ± 3.26 | 49.24 ± 8.73 | 49.60 ± 9.4 | 50.56 ± 7.97 |
| Mean healthy trees | | 37.48 ± 11.89 | 48.39 ± 17.28 | 22.49 ± 15.72 | 36.12 ± 10.72 |

[a]Value is a mean of % growth reduction for all cankers in that age class for that tree, if infected. Number of cankers for each mean is in parentheses. Values for uninfected trees represent one observation per age class.

[b]NA = data not available due to lack of cankering or non-dissected cankers in that portion of tree.

large variabilities between trees and within a tree indicating that a larger sample is required before conclusive results are possible.

C. heteronema was isolated from two of the four open cankers and from two of the six closed cankers. Fungal identification was verified by Dr. Kenneth Kessler, U.S. Forest Service, Carbondale, IL and Dr. Amy Rossman, U.S. Dept. Agric., Beltsville, MD. The low success of isolations is probably due to rapid invasion by secondary organisms of infected wood. Aspergillus, Alternaria, and Trichoderma species as well as bacteria were frequently isolated from discolored, dark tissues. Since C. heteronema is relatively slow growing, it may have been overgrown. An amber-colored reaction zone often surrounded the darkened tissues. C. heteronema was most often isolated at the interface between darkened and normal or amber-colored sapwood. The infected tissues extended laterally and vertically into the wood, especially in the vertical direction. The pathogen was most often isolated at the upper and lower limits of the canker near the healthy interface. In each case, it was necessary to cut into the tree to isolate C. heteronema. This fungus was not isolated from the surface of the bark.

Open cankers were larger in the sapwood than closed cankers (Figures 7,8,9). Callus tissue was extremely distorted. Cankers which were at one time open, later closed, or visa versa in some cases (Figure 10,11).

Oatmeal agar, oats with 2 percent water agar and potato dextrose agar produced thick fluffy mycelium with abundant sporodochia and amber-colored droplets after one month. When sterile water was added to oats before or after autoclaving, a dense fluffy mycelium with no sporodochia

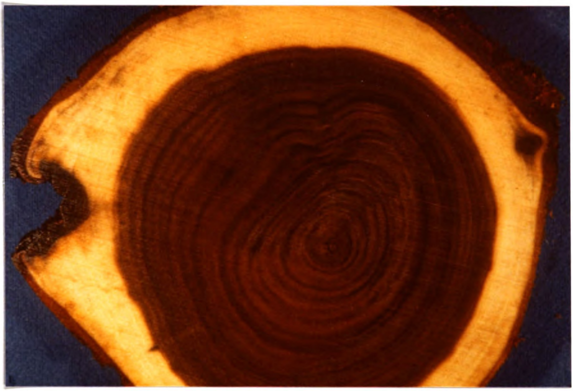


Figure 7. Cross section of open and closed nectria cankers on one black walnut trunk. Discolored areas are infected. Damage caused by closed cankers is limited compared to that caused by open cankers.

Figure 8. Closed nectria cankers on a black walnut trunk in southwest Michigan.

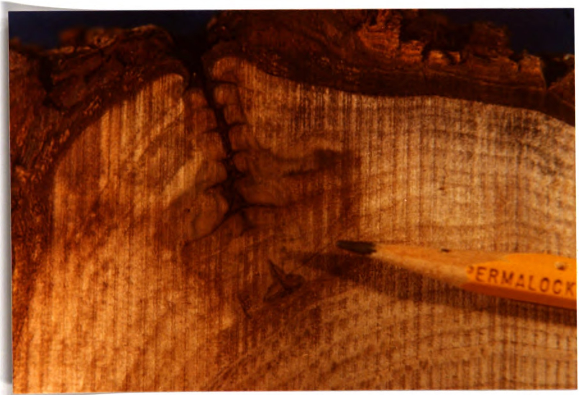



Figure 9. Close up of a cross section of a closed canker on a black walnut trunk in southwest Michigan.

Figure 10. Nectria canker on black walnut that was open, but now is closing.

Figure 11. Cross section of a similar nectria canker that was open, but now is closing.

was produced. Sporodochia were produced through the bark of autoclaved black walnut twigs. A thin mycelium covered the twigs as well. A zone of no growth on the twig existed when two isolates were placed in the agar on opposite sides of the twig and allowed to grow towards each other. Two percent water agar and V-8 agar produced thin colorless mycelium with no sporodochial formation. After six months, none of the cultures had produced perithecia. Condensation on the inside surface of the petri plate was greater when glass plates were used compared to plastic plates. In most cases after several months, cultures degenerated and produced small two-celled macroconidia instead of larger ones which were produced earlier.

## DISCUSSION

Nectria canker was more likely to be severe on sites at higher elevations or on wetter soils. However, these two factors explained only 35 percent of the variability in nectria canker severity on black walnut. Sites at higher elevation were usually on glacial till material. Glacial till material was more hilly. Hilly terrain was more likely to have cold pockets due to depressions and kettles. The glacial till plains and terminal moraines also had stands on hill tops which constituted an upland situation. Black walnut growing in depressions or kettles were much more likely to have severe nectria canker than black walnut growing on uplands. This could explain why not all sites on till material or at high elevations had high disease levels.

A similar situation existed for black walnut on outwash material. Most outwash sites were wetlands or uplands. Wetlands had high disease levels, uplands did not. Therefore, some black walnut on outwash sites had severe disease, some did not. Kettles, depressions and wetlands are all cold pockets (areas where cooler air accumulates). Since the factors causing low spots in hilly areas are different than the factors causing wet spots on flat land, it was not surprising that site factors such as glacial material, soil type and water table were only weakly correlated with nectria canker severity.

Soil types were not associated with presence of wetlands. This is because in the survey, sites were considered wet if standing water was within 200 m. In the soil studies of 30 of the survey sites, soils were considered poorly drained if mottles were present near the surface of the soil. In the survey analysis, site wetness was associated with disease levels, but in the soil studies, soil drainage and approximate depth to the water table were not. This is because trees were growing adjacent to the wetlands but not in them. Often the depth to the water table under a tree was two meters or more even though the tree was on flat land, within 200 meters of a wetland. This implies that some wetlands were the result of locally perched water tables. Since depth to water table was not correlated with nectria canker severity, but the presence of wetlands was, the effect of these wetlands was probably on the atmosphere, thus affecting the areal parts of the tree and the fungus more than the wetlands affected the soil and root systems of the trees.

In the Russ Forest Plantation, nectria canker infection was greatest on black walnut in the late 1970's. This further implies that atmospheric conditions may affect nectria canker severity since yearly variation in disease levels is often due to environmental factors. Tree stems between the ages of 22 and 24 years old had higher levels of infection. The average age of tree sections was 30 years old. All trees were planted 40 years ago. Therefore, it was about 10 years after planting before the trees were at the height of the sections sampled.

$$1945 + 10 \text{ years} + 23 \text{ years} = 1978$$

1978 is the year with highest infection levels. Peak years of infection could be due to favorable environmental factors which vary from year to year or due to especially susceptible host ages, since all of the black walnut trees in the plantation were the same age. The curves in Figures 5 and 6A have similar shapes. Merrill and Finley (1981) reported susceptible ages for nectria canker on black walnut in Pennsylvania with most infections occurring before tree sections were five years old. Differences in the results of this study and the results of their study could be explained if the age of infection corresponds to the years environment was favorable to disease. Merrill and Finley postulated that five years was the age at which branches became shaded. Following infection of shaded branches, branch cankers could have extended down the branch to the trunk as the branches died. Merrill and Finley studied shade tolerant and shade intolerant species and attributed black walnut's early age of infection to its shade intolerance. The present study indicates that other environmental factors are more important than the age or shading of the tree. Brandt (1964) reports that trees are most susceptible between two and 20 years old. Although this may be the situation for other tree species, it is not for black walnut in Michigan.

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Site factors were observed to be associated with severe nectria canker in other studies. Nectria canker on apple was associated with fog and high precipitation, moderate temperatures and a shorter growing season (Durbin and English, 1975a). Sites on terminal moraines (Graves, 1919), hilly or rugged areas (Ashcroft, 1934) or higher elevation (Brandt, 1964; Grant and Childs, 1940) also were associated with severe nectria canker. However, no association with aspect of the site was determined (Grand and Childs, 1940; Kienholz and Bidwell, 1938). Nectria canker was associated with wet soils (Brandt, 1964; Kienholz and Bidwell, 1938), lakes (Anderson and Mosher, 1979; Welch, 1934) and cold pockets (Ashcroft, 1934; Brandt, 1964). Spaulding et al (1936) reported that nectria canker was severe in dense forests, but not in open areas.

In this study, there were no high correlations between vigor as measured by dbh, competition as measured by presence of clearings, or canker shape and the number of cankers/tree in the Russ Forest Plantation. Dbh was not correlated with disease severity but was correlated with size of canker for other host species (Lortie, 1969). Diameter was positively correlated with disease severity for oaks and birches but negatively correlated with nectria canker incidence for maples (Kienholz and Bidwell, 1938). Grant and Childs (1940) found the opposite was true for maples and birches, dbh was positively correlated to nectria canker severity. However, these studies were not done on even-aged stands and may reflect differences other than vigor. Nelson (1940) found that tulip poplar with closing cankers increased dbh and basal area more quickly than trees with open cankers, but there was no relationship between rate of closing and rate of increase of basal area.

Some workers have reported 54 to 100 percent of nectria cankers that were dissected were associated with branch stubs or crotches (Kienholz and Bidwell, 1938; Kress and Wood, 1974; Lortie, 1969). These studies also described cankers associated with dormant buds, stem wounds, borer injury, wounds from snow, wind and frost cracks, and rubbing injuries. Grant and Spaulding (1939) found that 29 percent of dissected nectria cankers were associated with dead branch stubs, 27 percent with dead branch remnants and 15 percent with axils of living branches. They stated that usually infection of branches greater than 0.5 inch diameter near the crotch resulted in cankers. When branches less than 0.5 inch diameter were infected near the crotch, the branch died and no canker resulted. I have made no effort to separate dead branch stubs and remnants from living branches or to separate branches by size. However, only 31 percent of the cankers were associated with branch stubs. This is lower than other studies. Many of the hard-to-see closed cankers showed no apparent wound, but may have been initiated from minute branch traces or insect wounds. In Ashcroft's study (1934) of nectria canker on black walnut, branch stubs or crotches were associated with some cankers. Still other cankers were not associated with branch stubs, but instead started from a swelling and cracking of the bark. This also may be the case in Michigan. I have confirmed Gravatt's report (1933) that secondary insects were associated with nectria cankers.

Nectria canker may not significantly reduce diameter growth in black walnut. However, samples were small and results are not conclusive. Since diameter of each black walnut tree at Russ Forest

Plantation D46 was recorded and each tree mapped, future research should include remeasurements of dbh to determine diameter growth rates for infected and uninfected trees over a period of years. Nectria canker of yellow birch resulted in a loss of 39 of the 65 board feet in an average saw log, also not including loss in veneer quality (Anderson and Mosher, 1979).

## RECOMMENDATIONS

Other studies combined with the results of this study may provide some insight into future avenues of research. It is not this author's intention for this section of the thesis to prove why nectria canker is severe on black walnut in some areas but not in others. The intention is to point out studies that may provide base-line data for future research proposals. Nectria canker was severe in cold pockets in this study. Cold pockets are characterized by cooler temperatures and increased humidity. Infection levels varied from year to year, indicating that environmental climatic factors may affect disease severity. Although no information was available for relative humidity over the last 30 years, some temperature and precipitation data from a weather station nine miles west of Russ Forest were correlated to nectria canker infection. Multiple linear stepwise addition regressions were conducted using percent of 200 cankers which were initiated each year as the dependent variable. Total precipitation and average temperature for each month and for each year were used as the independent variables. The STAT 4 statistical package was used for all analyses. When only monthly temperature (1960-1983) was used, average temperature for October and February was negatively correlated with number of infections for each year ($\underline{R}^2$ = 0.47, $\underline{P}$ = 0.001). When only monthly precipitation (1960-1983) was used, total precipitation for May, August and October was positively correlated with number of infections for each year ($\underline{R}^2$ = 0.51, $\underline{P}$ = 0.002). Mean February and October temperature as well as May, August and October total precipitation were regressed against percent cankers initiated, for the years 1960-1983 (Figure 12). Other months were not significantly correlated in regression equations ($\underline{P}$ = 0.10). May ($P_1$) and August ($P_2$) total precipitation, combined with February ($T_1$) and October ($T_2$) average temperatures, were correlated with percent cankers initiated ($\underline{R}^2$ = 0.67, $\underline{P}$ = <0.0005). This relationship is summarized in Figure 12. The regression equation was $Y = 0.579 + 0.5319 P_1 + 0.4708 P_2 - 0.5915 T_1 - 0.5377 T_2$. When only average annual temperature was involved, it also was negatively correlated with number of infections, but to a lesser extent ($\underline{R}^2$ = 0.31, $\underline{P}$ = 0.005). If only total annual precipitation was used, it was positively correlated with number of infections, but to a lesser extent ($\underline{R}^2$ = 0.35, $\underline{P}$ = 0.002). When only annual total precipitation and annual mean temperature were regressed against number of cankers initiated, the correlation was not as large ($\underline{R}^2$ = 0.43, $\underline{P}$ = 0.003). Annual and monthly values were analyzed separately, since annual values are dependent on monthly values, negating one of the rules of multiple regression.

When the growing season, or the number of consecutive days per year during which minimum temperatures were above 32, 28, 24, 20 or 16$^o$ F were regressed, they were not correlated to annual number of infections ($\underline{P}$ = 0.10) except in the case of growing season above 24$^o$ F which did not explain a large amount of the variation in number of infections ($\underline{R}^2$

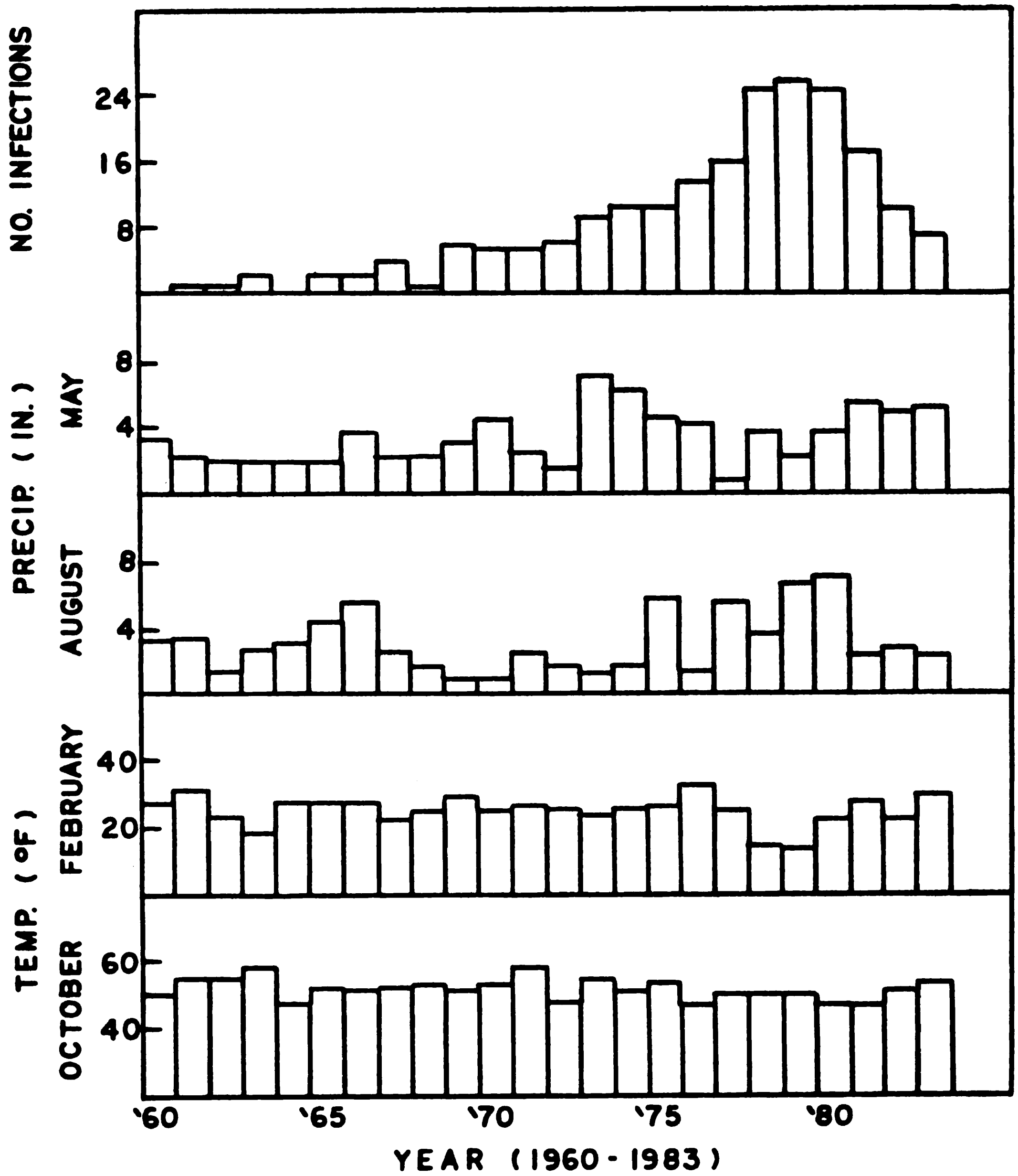


Figure 12. Relationship between year of nectria canker infection for 200 cankers, total May and August precipitation and average February and October temperature for 1960-1983 ($\underline{R}^2$ = 0.67, $\underline{P}$ = <0.0005). No cankers were initiated before 1961. Precipitation and temperature were measured at Dowagiac, Michigan, 9 miles west of the cankered site, and compiled by the Michigan Weather Service in cooperation with the ESSA-Weather Bureau, U.S. Department of Commerce.

= 0.15). The number of days in the year during which maximum temperatures were less than 0° F did not explain the variability in number of infections ($R^2$ = 0.17, $P$ = 0.07). The same was true for the number of days in the year during which maximum temperatures were less than 32° F ($R^2$ = 0.08, $P$ = 0.22) or were greater than 90° F ($R^2$ = 0.16, $P$ = 0.08). Day degrees base 40, 45, 50 and 55° F were not significantly correlated with annual number of infections ($P$ = 0.10), nor were heating day degrees or cooling day degrees base 65° F ($P$ = 0.10).

When annual or February and October mean temperatures were cooler, disease was more severe. Cooler February and October temperatures could prolong the period of fungal activity and shorten the growing season of the tree. Cold temperatures in February could cause injury to the tree, providing more wounds for successful infection. However, the latter is unlikely since most cold injuries occur in late spring when the tree is active and can restrict growth of N. galligena. Cold pockets may have cooler mean February and October temperatures than do uplands.

When May and August precipitation was greater, nectria canker infection was also greater. Ascospore release was greater when perithecia were wetted, especially when wetted and then dried (Lortie and Kuntz, 1963; Spaulding et al, 1936). Conidia were released during warm rains (Lortie and Kuntz, 1963). May and August are at the beginning and end of the black walnut growing season, respectively. A wetter May and August may result in increased spore release and infection frequency during a time when black walnut is not able to limit fungal colonization. Cold pockets may have wetter May and August conditions than uplands because of fog. Fog (100% relative humidity) would provide wet conditions during the evening until early morning, with drying during the middle of the day.

According to the Palmer Index, 1945 to 1964 were generally draughty years, with the exception of 1950-52 (Figure 13). The rise in precipitation levels in 1964-1978 corresponded with occurrence of nectria canker since none of the 200 cankers were observed to occur before 1961. Perhaps moisture was not available for spore dispersal in adequate quantities for successful infection during susceptible periods before 1960.

The climate of southwest Michigan is influenced by Lake Michigan. Annual temperatures are warmer than other parts of Michigan (Figure 14). Thus, winter and fall temperatures are more moderate since lake effects are greatest in fall and winter. These moderate temperatures could result in an increased period of pathogen activity caused by a shorter time period during which temperatures are too low for fungal activity. N. galligena spores can be released, germinate and grow at temperatures as low as $0^{o}$ C (Ashcroft, 1934; Lortie, 1964; Lortie and Kuntz, 1963). However, it is not certain if these temperature differences are enough to be significant.

The diseased area also lies within a zone known as the "Snow Belt." This region is characterized by increased annual precipitation and cloudiness, especially in the fall and winter (Figures 15 and 16). This results in an increased frequency of snow and ice storms in this region. The "Snow Belt" occurs parallel to Lake Michigan and somewhat inland from the lake. Black walnut trees were often severely cankered on sites where frequent snow and ice storms occurred (Brandt, 1964; Grant and Childs, 1940; Roth and Hepting, 1954). Wounds at branch crotches, made

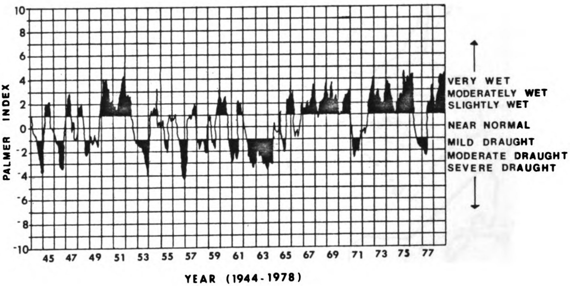


Figure 13. Palmer meteorological draught index for the southwest lower climatic division in Michigan (1944-1978). (From Nurnberger, 1980.)

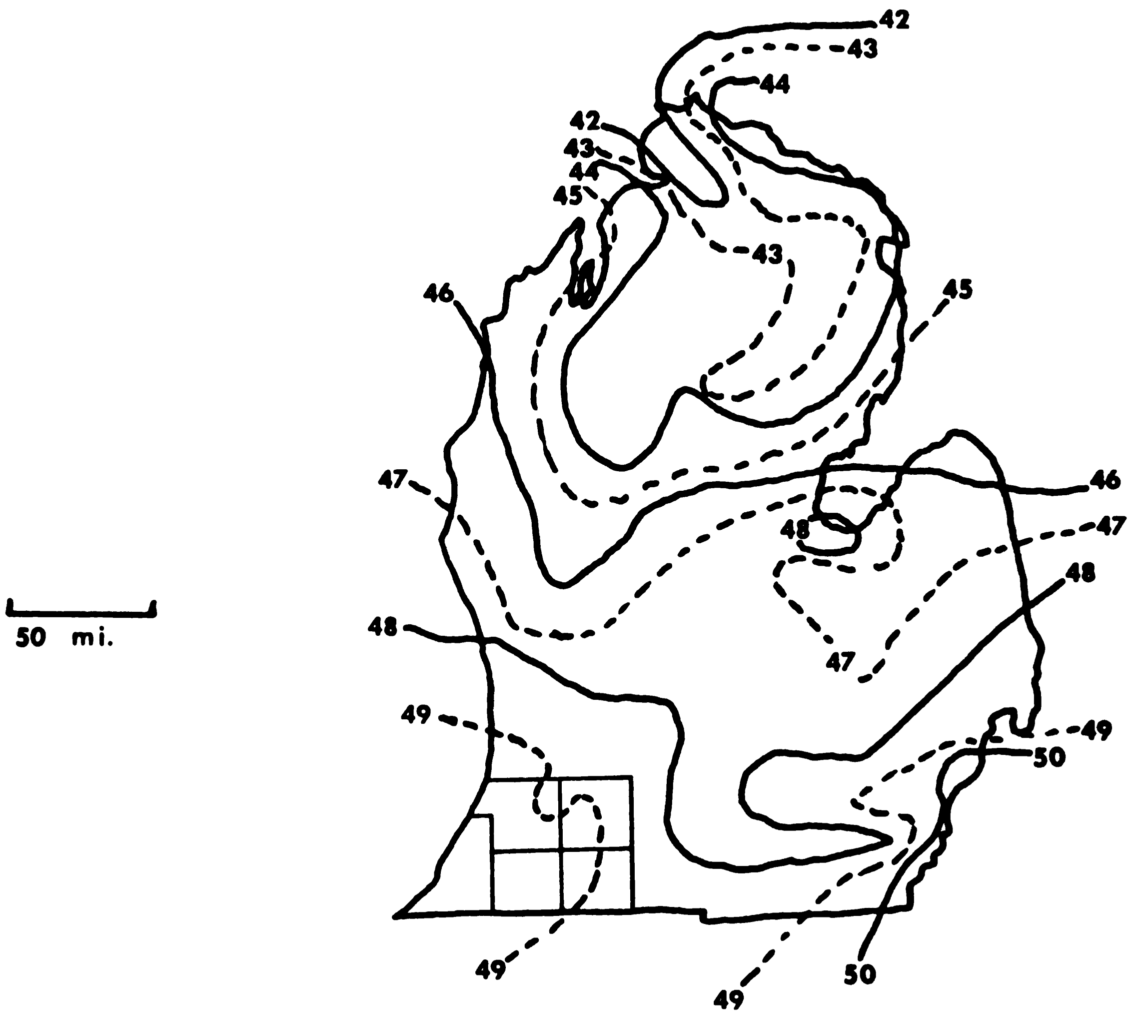


Figure 14. Annual mean temperature of southern Michigan ($^{o}F$), 1940-1969, published by the Office of Climatology, Michigan Department of Agriculture, East Lansing.

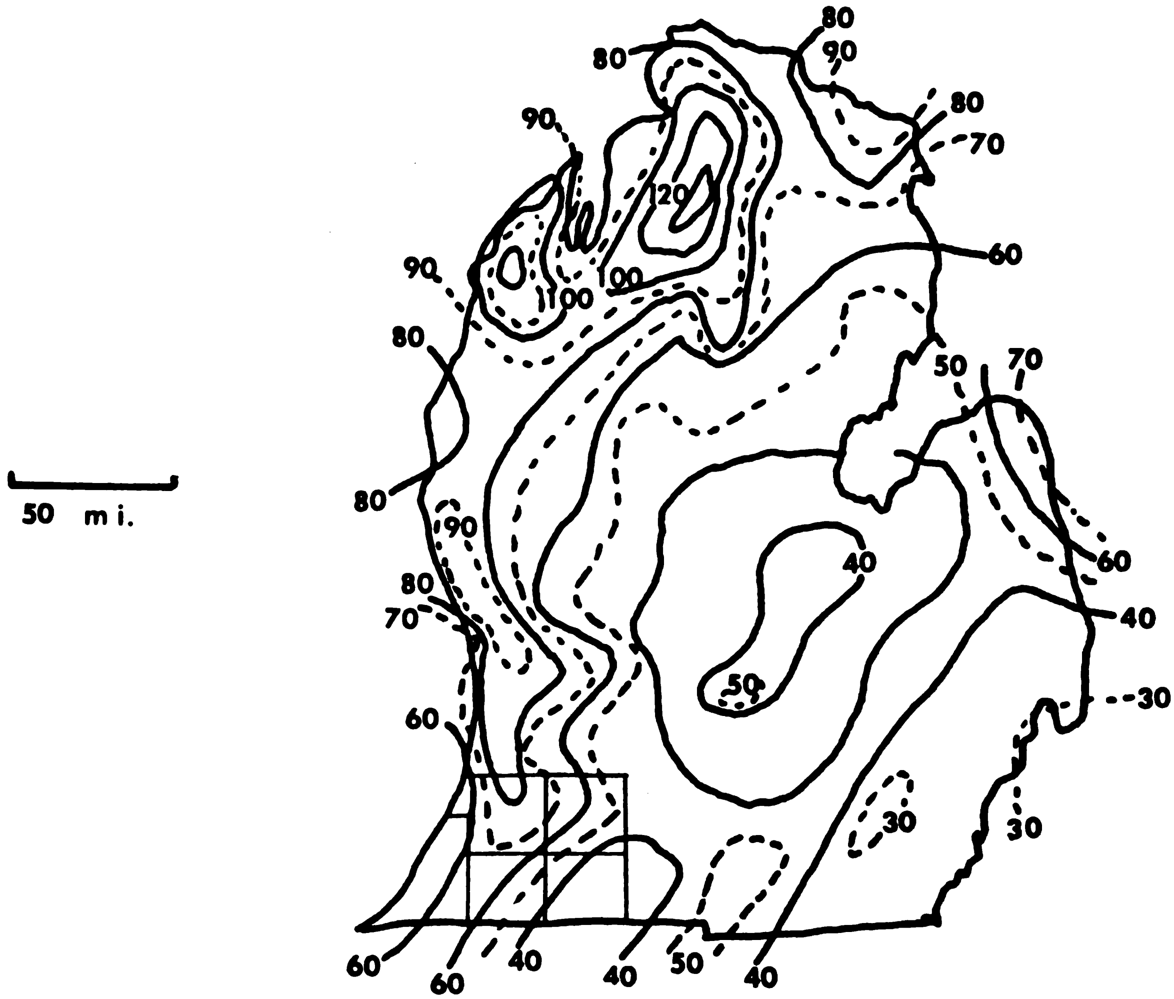


Figure 15. Annual mean snowfall of southern Michigan (inches), 1940-1969, published by the Michigan Weather Service, East Lansing.

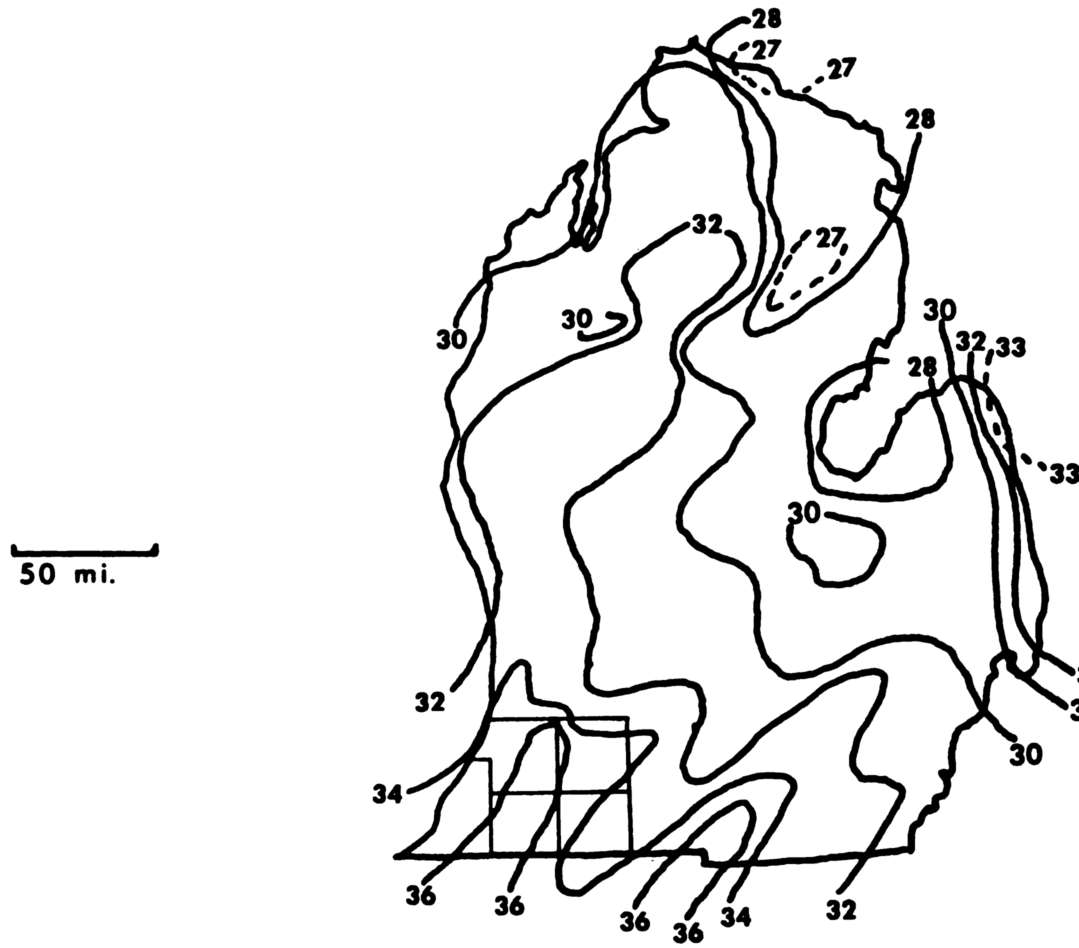


Figure 16. Annual mean precipitation of southern Michigan (inches), 1940-1969, published by Office of Climatology, Michigan Department of Agriculture, East Lansing.

when heavy loads of ice or snow, bend or break branches, may be infection courts for nectria canker (Grant and Spaulding, 1939; Lortie, 1969). Increased fall precipitation may result in increased spore release and infection while the tree is dormant, as discussed earlier.

Several workers report that trees were able to close over cankers when soils were fertile (Gravatt, 1933; Brandt, 1964). In Michigan, unpublished data from a study by Robertson et al (1975) indicated that soil fertility may be low, especially for calcium levels, within the region of abnormally high nectria canker incidence (greater than five percent infection of black walnut per stand) as illustrated by Figure 17. The same study indicates that soil pH also may be low for the diseased area (Figure 18). Many nutrients, including calcium are less available to plants in acid soils. Trees growing on poor soils will resume growth later in the spring and become dormant earlier in the fall. This decreased growing season could allow a longer period of activity for N. galligena to infect and colonize its host. The location of the region of high nectria canker incidence could be a result of the intersection of the "Snow Belt" with the occurrence of acid, infertile soils.

Similar soil and climatic factors could be involved in Pennsylvania. The valleys are regions of high fog frequency in the fall and high ice storm frequency in the winter. Both the Michigan and Pennsylvania sites overlie early Mississippian shales which are usually low in pH and calcium levels (personal communication, Dr. H. A. Winters, Dept. of Geography, Michigan Sate University). Therefore, it appears that conditions which shorten the host growing season and/or lengthen the period when the fungus is active, contribute to nectria canker severity on black walnut.

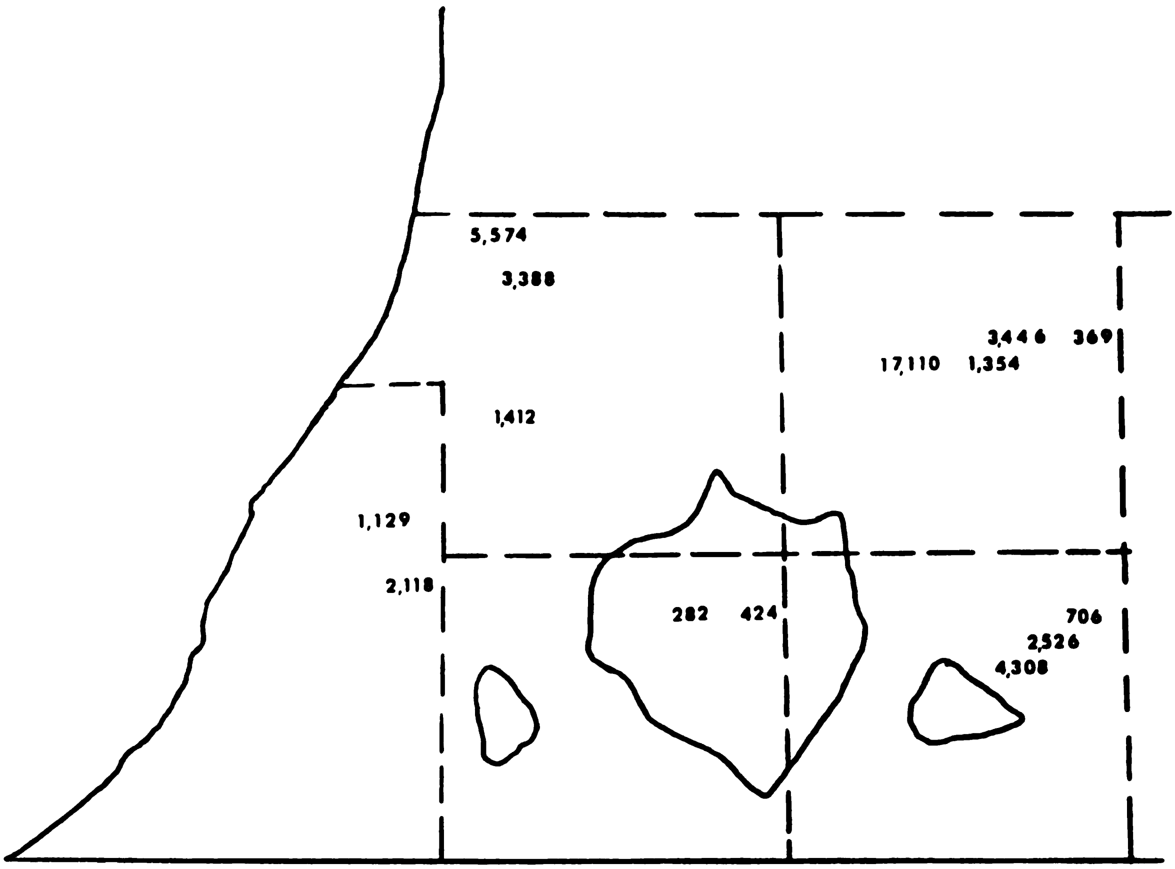


Figure 17. Summary of calcium levels (lbs/acre) of the C horizon in southwest Michigan (adapted from Robertson et al, 1975). Regions where more than 5% of black walnut per stand were infected with nectria canker are outlined.


Figure 18. Summary of pH levels of the C horizon in southwest Michigan (adapted from Robertson et al, 1975). Regions where more than 5% of black walnut per stand were infected with nectria canker are outlined.

Cultural morphology of C. heteronema indicated no differences between closed and open canker isolates. However, studies were not extensive and further studies should include accurate pathogenicity tests. Differences in tree genetic background were not investigated on an individual tree basis. Such differences could be responsible for the shape of the canker. The Russ Forest Plantation D-46, which has many infected black walnut trees, is probably from seed from the Chicago area; however, records are vague. If the stock is foreign, it is unlikely that diseased regions occur in southwest Michigan because of an especially susceptible native gene pool in that area. However, genetic resistance or immunity should be investigated in future studies.

In summary, there was preliminary evidence which indicated that poor soil fertility, cooler temperatures and increased precipitation or relative humidity may result in increased disease severity. It is possible that these factors or other unknown factors, such as differences in fungal virulence or host susceptibility result in pockets of high nectria canker incidence on black walnut. Now that we have some of the baseline data needed, the time is ripe to initiate detailed studies concerning the role of environment in nectria canker of black walnut.

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# GLOSSARY[a]

Basal area (F). The sum of the areas of cut stump surfaces that would be exposed if all trees were felled, usually in $ft^2$/acre. This may also be used to apply towards one tree's cut surface area (Basal diameter).

Clay films (S). A layer of clay covering the surface of a "clod" of soil or ped. This layer is deposited as water-carrying clay moves through the soil.

Consistency (S). The resistance of soil to disruption. A soil's cohesion or adhesion to itself. Levels range from loose to soft to hard.

Dbh or diameter at breast height (F). Diameter of the trunk of a tree at breast height. By convention, this is 4.5 ft. above the soil line.

Drainage class (S). The aeration level of the soil based on depth to mottles and subsoil color. Poorly drained = depth 6-20 in., subsoil mottled gray and yellow; moderately well drained = 20-40 in.; well drained = >40 in.

Glacial till (G). Unstratified or unsorted rock and soil deposited by the ice of a glacier. May have any proportion of sand, clay, silt and rocks.

Gleyed soil (S). Soil that is gray-colored due to long term saturation under anaerobic conditions. The soil minerals are in a reduced state. Mottles may be present. Gleyed soils are often colder because of their greater specific heat.

Kame (G). A steep sided knob-like hill of stratified soil or rock layers formed when water runs into a hole in the ice of a glacier. They are associated with interlobate moraines.

Lacustrine material (G). Materials (usually fine textured) deposited from standing or ponded water. Associated landforms are flat or gently sloping.

Microrelief (G). Small-scale, local differences in topography of the site.

Moraine (G). Deposits of glacial till, usually in hills or ridges, are formed at the margin of a moving ice sheet or when the backward melting equals the forward advance of ice. Moraine slopes are generally steeper than till plain or outwash slopes. End moraines or terminal moraines mark the furthest advance of the glacier.

Mottles (S). Spots or blotches in soil of one color interspersed in a matrix of another shade or color. Color differences are a result of differences in aeration levels (air bubbles) or wetted soils. Mottles are used to determine the wetness and drainage class of a soil.

Outwash (G). Material carried from the glacier by water and laid down in stratified deposits sorted into similar textures. Outwash plains are gently rolling (non-pitted) to rolling (pitted).

Parent material (S). The unconsolidated and chemically weathered material from which a soil forms by pedogenic processes.

Structure (S). The grade size and shape of peds or "clods" of a soil. Grade ranges from none to weak to strong. Size ranges from very fine to medium to coarse. Shape ranges from massive to plately to columnar to blocky to granular to single grained.

Surface geology (G). Landforms on the earth's surface, such as moraines, till plains, outwash plains, etc.

Texture (S). The relative proportions of sand, silt and clay in a soil. The presence of gravel, cobbles or boulders is also incorporated into the textural class. Common textures are sand, sandy loam, sandy clay loam, silty loam, gravelly clay, etc. The textural categories are determined by established standards.

Till plain (G). Deposits of glacial till, usually level to rolling, spread out between moraines while the glacier is rapidly retreating or melting.

[a]Terms followed by (S) are soil terms. Those followed by (F) are forestry terms; (G) are geology terms. The reader is referred to any basic textbook for more information. A few are listed here.

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# APPENDIX

Table I

Summary of the relationship between glacial deposition and stand percent infection rating in $X^2$ contingency tests of 166 nectria canker survey sites for black walnut in Cass, St. Joseph, Van Buren and Kalamazoo counties.

| Stand percent infection | Terminal moraine | Till plain | Outwash | Glacial drainage/lacustrine |
|---|---|---|---|---|
| | Number of sites observed | | | |
| 0 | 15 | 8 | 44 | 6 |
| 1-5 | 13 | 4 | 14 | 4 |
| 6-15 | 6 | 2 | 6 | 0 |
| 16-25 | 6 | 2 | 2 | 0 |
| 26-50 | 7 | 1 | 3 | 0 |
| 51-75 | 7 | 1 | 2 | 0 |
| >75 | 8 | 1 | 4 | 0 |
| | 62 | 19 | 75 | 10 |
| | $X^2$ = 28.781 | | *P* = 0.05 | |

Table II

Summary of the relationship between soil type and stand percent infection rating in $X^2$ contingency tests of 30 nectria canker survey sites for black walnut in southwest Michigan.

| Stand percent infection | Sandy | Clayey | Rocky | Loamy |
|---|---|---|---|---|
| | Number of sites observed | | | |
| 0 | 5 | 2 | 0 | 0 |
| 1-5 | 5 | 4 | 2 | 2 |
| >75 | 5 | 3 | 1 | 1 |
| | 15 | 9 | 3 | 3 |

$X^2 = 3.150$ $\underline{P} = 0.79$

Table III

Summary of the relationship between C horizon texture and stand percent infection rating in $X^2$ contingency tests of 21 nectria canker survey sites for black walnut in southwest Michigan.

| Number of sites observed | | |
|---|---|---|
| Stand percent infection | Gravelly | Sandy |
| 0 | 1 | 5 |
| 1-5 | 6 | 2 |
| >75 | 6 | 1 |
| | 13 | 8 |

$X^2 = 7.471$ $\quad$ *P* = 0.02

Table IV

Summary of the relationship between micro-relief and stand percent infection rating in $x^2$ contingency tests of 30 nectria canker survey sites for black walnut in southwest Michigan.

| Stand percent infection | Flat | Rolling | Steep |
|---|---|---|---|
| | Number of sites observed | | |
| 0 | 6 | 1 | 0 |
| 1-5 | 4 | 9 | 0 |
| >75 | 4 | 0 | 6 |
| | 14 | 10 | 6 |

$x^2 = 24.207$     *P* = 0.0005

Table V

Summary of the relationship beween wetland association and stand percent infection rating in $\chi^2$ contingency tests of 30 nectria canker survey sites for black walnut in southwest Michigan.

| Stand percent infection | (-) | (+) |
|---|---|---|
| | Sites observed | |
| 0 | 4 | 3 |
| 1-5 | 11 | 2 |
| >75 | 4 | 6 |
| | 19 | 11 |
| $\chi^2$ = 4.996 | $P$ = 0.08 | |

Table VI

Summary of the relationship between slope position and stand percent infection rating in $X^2$ contingency tests of 30 nectria canker survey sites for black walnut in southwest Michigan.

| Stand percent infection | Upper flat | Upper slope | Middle slope | Lower slope | Lower flat |
|---|---|---|---|---|---|
| | Number of sites observed | | | | |
| 0 | 4 | 0 | 1 | 1 | 1 |
| 1-5 | 2 | 5 | 2 | 2 | 2 |
| >75 | 0 | 1 | 3 | 1 | 5 |
| | 6 | 6 | 6 | 4 | 8 |
| | $X^2$ = 15.029 | | *P* = 0.06 | | |

Table VII

Summary of the relationship between aspect and stand percent infection rating in $X^2$ contingency tests of 23 nectria canker survey sites for black walnut in southwest Michigan.

| Stand percent infection | North | East | South | West |
|---|---|---|---|---|
| | Number of sites observed | | | |
| 0 | 1 | 2 | 2 | 0 |
| 1-5 | 4 | 2 | 4 | 1 |
| >75 | 4 | 1 | 0 | 2 |
| | 9 | 5 | 6 | 3 |

$X^2 = 6.80$    $P = 0.34$

Table VIII

Summary of the relationship between mode of glacial deposition and stand percent infection rating for $X^2$ contingency tests of 30 nectria canker survey sites for black walnut in southwest Michigan.

| Stand percent infection | Lacustrine | Kame | Outwash | Moraine | Till plain |
|---|---|---|---|---|---|
| | Number of site observed | | | | |
| 0 | 1 | 0 | 6 | 0 | 0 |
| 1-5 | 1 | 1 | 4 | 0 | 7 |
| >75 | 0 | 0 | 6 | 3 | 1 |
| | 2 | 1 | 16 | 3 | 8 |
| | $X^2$ = 17.815 | | *P* = 0.02 | | |