DECLINES OF UNKNOWN ETIOLOGY

Spatial and Temporal Analysis of Citrus Blight Incidence in 'Valencia' Orange Groves in Central Florida

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ABSTRACT. Increase of incidence of citrus blight in two 'Valencia' on rough lemon groves in central Florida over an 8 and 13 year period was evaluated. Blight distribution was nonrandom: trees next to affected trees developed blight more frequently than nonadjacent trees. Tree-to-tree spread increased with planting density. Increases in disease incidence from 9 to 31 and 26 to 77% were linear with time. Blight increase in 14 other central Florida groves on rough lemon was also linear with time. From the analyses, we believe that any possible pathogen is likely to be soilborne or have very limited aerial movement.

Index words. citrus, decline rates, quantitative epidemiology, randomness tests, disease-progression curves.

Citrus blight is the most serious disease problem of Florida citrus. Blight has been known to occur in Florida for over 100 years, but its etiology remains unknown. Visual symptoms of affected trees include zinc deficiency of leaves, wilting of a sector or entire canopy of the tree, delayed flush, thin foliage, dieback, and production of water sprouts (21). Symptoms of diseased trees become progressively worse with time, but trees usually do not die. Affected trees are nonproductive and must be replaced. Because a number of factors can cause similar symptoms (9), citrus blight is diagnosed by reduced uptake of water when it is injected into the large roots and the trunk (5), and accumulation of zinc and water-soluble phenolics in trunk wood (22, 25).

Blight symptoms can appear on trees of any age once they reach bearing age (30). Sweet orange and grapefruit are varieties most severely affected by blight (8). Incidence of citrus blight varies considerably among rootstocks. Trees on rough lemon are much more susceptible than trees on other commonly used stocks in Florida (21). In evaluations of current rootstocks, trifoliate orange, Carrizo citrange and Alemow (24, 28, 29) were found to be moderately susceptible.

All attempts to transmit or reconstitute blight from affected trees have been unsuccessful. No causal agent has been shown to cause blight. A fastidious xylem-limited bacteria (2, 12, 23) and soilborne factors (3) are two popular hypotheses which have been proposed as possible causal agents.

An analysis of the distribution and rate of increase of diseased plants often provides useful information about the type of agent causing the disease (32). In this study, we surveyed blight incidence and distribution annually in two central Florida groves. These data were analyzed to determine if the probable type of causal agent of the disorder could be deter-

[1]Deceased.
[2]Retired.

mined from patterns of disease progression.

MATERIALS AND METHODS

Survey procedure. A 16.2-ha nucellar Valencia/rough lemon grove, planted in 1965 near Winter Garden, Florida, was selected as the primary site for this study. The grove is under excellent management and is on deep Astatula fine sand (hyperthermic, uncoated typic quartzipsamments). Declining trees were first noticed in 1974. The first survey was taken in November 1975. Each tree was rated as follows: healthy; blight affected; a replant; or other (lightning damaged, foot rot, heart rot, freeze damaged, etc.). Since low levels of foot rot and lightning injury were the only factors besides blight contributing to young tree loss in this grove, replant records were used to estimate number of blight-affected trees from 1970-74. Trees were planted with 7.6 x 7.6 m spacing. Surveys were taken annually except in 1976.

We also analyzed blight incidence and distribution from a 'Valencia'/ rough lemon grove near Avon Park, Florida. This grove was planted in 1955 on Pomello sand (sandy, siliceous, hyperthermic arenic haplohumod). Tree spacing was 4.6 x 9.1 m. The grower first became aware of the blighted condition of trees in 1964. Annual surveys were made in a 5.6-ha portion in the southwest corner of the grove from 1965-77. The tree rating system was the same as for the Winter Garden grove.

Additional blight incidence recorded by Grimm *et al.* (11) from 14 groves in central Florida was also analyzed for comparison with our data. Scion varieties in these groves included Valencia and Hamlin oranges and Duncan and red grapefruits. All varieties were on rough lemon rootstock.

Blight diagnosis. Zinc levels of trunk wood and water uptake were determined by previously described methods (5, 27, 31) to confirm visual diagnosis of tree condition. Representative healthy trees and trees in early stages of blight were tested.

Statistical analyses. The assumption made for this study was that blight is caused by a pathogen and the analyses employed were methods used for plant diseases. Growers replaced blight-affected trees with young, healthy replants annually. These replants were considered as blight-affected tree sites in subsequent surveys. Distribution of blight was analyzed by two tests for randomness. In the doublet analysis, a doublet is two adjacent diseased plants (32). When more than two adjacent infected plants occur, the number of doublets is one less than the number of diseased plants in a row. Our study sites were divided into smaller, more homogenous subunits and doublets were counted. The expected number of doublets was determined by

$$E(Dc) = [N-r][m(m-1)/N(N-1)] \quad (1)$$

where E(Dc) is the number of expected doublets corrected for the 'missing' trees when all rows are extended into a single row, r is the number of rows combined, m is the number of diseased plants, and N is the total number of plants (16). The standard deviation was calculated as

$$\sigma = \sqrt{E(Dc)} \quad (2)$$

(32).

The other test of randomness was the ordinary runs analysis. "With two types of symbols, a run is defined as a succession of one or more identical symbols which is preceded and followed by a different symbol or no symbol at all" (10). The expected number of ordinary runs is determined by

$$E(U) = 1 + 2m(N-m)/N \quad (3)$$

where E(U) is the observed number of ordinary runs, m is the observed number of infected plants in a row and N is as described above. The standard deviation of U is

$$\sigma = [2m(N-m)[2m(N-m)-N]/[N^2(N-1)]]^{1/2} \quad (4)$$

For the doublet and the ordinary run analyses, the test for randomness was

$$Z = [(\text{Observed} + 0.5) - \text{Expected}]/\sigma \quad (5)$$

Distribution is nonrandom if Z > 1.64 (P = 0.05) and 2.33 (P = 0.01). Distribution is clumped when Z is positive for doublets and negative for ordinary runs.

Influence of tree spacing was ascertained by comparing the degree of nonrandomness by ordinary runs determined within a row versus that observed between the rows in the two study sites. Z values were determined for each year's data and differences compared by the Student's *t*-test.

Several transformations were employed to evaluate disease progression with time. According to van der Plank (33), disease can increase in time in several ways. If the pathogen multiplies within the field and spreads from leaf to leaf or plant to plant logistically, it is called a "compound interest" disease (CID). CID progression is linearized against time by

$$Y = \ln[y/(1-y)] \quad (6)$$

where y is the proportion diseased. If the pathogen does not spread directly from plant to plant within the field, it is called a "simple interest" disease (SID) and disease progression is linearized by

$$Y = \ln[1/(1-y)] \quad (7)$$

where y is as described as above.

In addition, the Gompertz transformation as described by Berger (1) was used since it is useful when disease increase is skewed to the right and is intermediate of the CID and SID models. This transformation equation is

$$Y = \ln[-\ln(y)] \quad (8)$$

where y is as described above.

RESULTS

Declining trees in the Winter Garden and the Avon Park groves exhibited typical blight symptoms. Visual diagnosis was confirmed by water uptake and wood zinc tests. Trees with early blight symptoms took up 181 ml water/24 hr and had 11 ppm zinc in trunk wood; while healthy-appearing trees took up more than a liter of water/24 hr and had 3 ppm zinc.

The incidence of blight-affected tree sites in the Winter Garden grove increased from 9.3% in 1975 to 31.4% in 1982 (Table 1). The average annual rate of increase was 3.2%, with a range of 1.7-5.3%. Blight incidence in the Avon Park grove increased from 26.2% in 1965 to 79.4% in 1977. The observed annual increase ranged from 0.6 to 6.7% and averaged 4.4%. Blighted trees were distributed nonrandomly (i.e. infected trees were clumped) in the grove, based on Z values (P = 0.01) for both the doublet and ordinary runs analyses (Table 1). More trees adjacent to infected trees or replants became infected than nonadjacent trees. No significant correlation was found when the degree of clumping (Z values) was regressed against blight incidence as might be expected if a pathogen were spreading from plant to plant.

When blight spread was compared at the Avon Park grove within a row versus between rows, nonrandomness (P = 0.01) was greater within a tree row (trees 4.6 m apart) than between rows (trees 9.1 m apart) (Table 2). In the Winter Garden grove, which had a uniform plant spacing of 7.6

TABLE 1
COMPARISON OF TWO TESTS FOR RANDOMNESS OF BLIGHT-AFFECTED TREES IN TWO VALENCIA/ROUGH LEMON GROVES IN CENTRAL FLORIDA

Year	Affected (%)	Doublet† Exp.	Doublet† Obs.	Doublet† Z	Ordinary run‡ Exp.	Ordinary run‡ Obs.	Ordinary run‡ Z*
Avon Park, FL§							
1965	26.2	110.8	130	1.9	523.1	431	—6.4
1966	30.9	141.3	165	2.0	562.4	478	—5.5
1967	37.6	202.2	246	3.1	633.3	508	—7.2
1968	43.4	259.4	304	2.8	652.8	536	—6.5
1969	47.3	284.4	346	3.7	661.8	544	—6.5
1970	52.6	350.8	412	3.3	664.0	552	—6.1
1971	56.3	386.1	466	4.1	657.4	526	—7.3
1972	62.1	456.0	541	4.0	633.8	528	—6.8
1973	66.3	552.2	603	3.5	601.7	516	—5.2
1974	69.3	563.8	655	3.8	573.1	500	—4.6
1975	74.5	646.0	748	4.0	514.6	451	—4.5
1976	78.8	719.7	822	3.8	456.6	404	—4.2
1977	79.4	742.1	850	4.0	447.5	382	—5.3
Winter Garden, FL¶							
1975	9.3	34.4	60	4.4	486.5	422	—5.9
1977	13.4	66.4	111	5.5	664.9	547	—9.3
1978	15.1	90.0	148	6.2	776.7	631	—9.8
1979	19.2	125.8	194	6.1	892.2	718	—10.2
1980	24.7	186.5	262	5.5	1040.5	855	—9.3
1981	26.1	225.9	303	5.1	1094.6	858	—11.3
1982	31.4	275.1	397	7.4	1180.4	944	—10.5

*Distribution nonrandom if $|Z| > 1.64$ ($P = 0.05$) and 2.33 ($P = 0.01$).
†Doublets calculated by method of van der Plank (32). Distribution is clumped when Z is large and positive.
‡Ordinary run calculated by method described in Madden *et al.* (16). Distribution is clumped when Z is large and negative.
§No. trees = 1328, row spacing 4.6 x 9.1 m.
¶No. trees = 2756, row spacing 7.6 x 7.6 m.

TABLE 2
RELATION OF TREE SPACING AND RANDOMNESS OF BLIGHT-AFFECTED TREES IN TWO VALENCIA/ROUGH LEMON GROVES IN CENTRAL FLORIDA DETERMINED BY ORDINARY RUNS ANALYSIS

Tree spacing (m)	Direction	Avg. Z value
Avon Park		
4.6	North-south	—6.75
9.1	East-west	—5.84
P value*		<0.01
Winter Garden		
7.6	North-south	—9.52
7.6	East-west	—9.63
P value*		NS

*P value for significant differences by Student's *t* test.

x 7.6 m, neither direction had significantly more infected trees.

High correlations resulted when blight incidence was regressed against time in both the Winter Garden ($r^2 = 0.97$) and the Avon Park ($r^2 = 0.99$) groves (Table 3). These coefficients were as high as any resulting from CID, SID, or Gompertz transformations.

Slopes of regression lines of blight incidence resulted in rate increases of 4.5 and 3.5%/yr (Fig. 1) in the Avon Park and Winter Garden grove, respectively. This corresponds with the average annual rate increase already mentioned (Table 1). However, when incidence was adjusted to compensate for differences in tree spacing, disease progression at Avon Park

TABLE 3
COMPARISON OF THREE TRANSFORMATIONS OF BLIGHT INCIDENCE DATA FROM TWO VALENCIA/ROUGH LEMON GROVES IN CENTRAL FLORIDA BY LINEAR REGRESSION ANALYSIS

Grove	r^{2*}			
	Nontrans-formed	CID	SID	Gompertz
Avon Park	.992	.994	.987	.996
Winter Garden	.974	.988	.964	.986

*Transformations were CID = $\ln[y/(1-y)]$; SID = $\ln[1/(1-y)]$; and Gompertz = $-\ln[-\ln(y)]$; where y = proportion diseased.

decreased to 3.3%/yr and was, therefore, essentially the same as that in the Winter Garden grove.

Blight incidence from 14 other central Florida citrus groves reported by Grimm *et al.* (11) was analyzed and compared with our results. In all groves, there was a high correlation of linearity of blight incidence with time (Table 4). When the proportion of blight-affected tree sites was transformed by the CID, SID and Gompertz formulas, the transformations with time did not appreciably increase statistical fit. Slopes of regression lines plotted over grove age were also observed to be similar regardless of incidence, although results were more variable than those in our study groves.

DISCUSSION

Determination of disease patterns and rates of spread in the field can reveal much information on the etiology of a plant disease. If a random pattern of infected

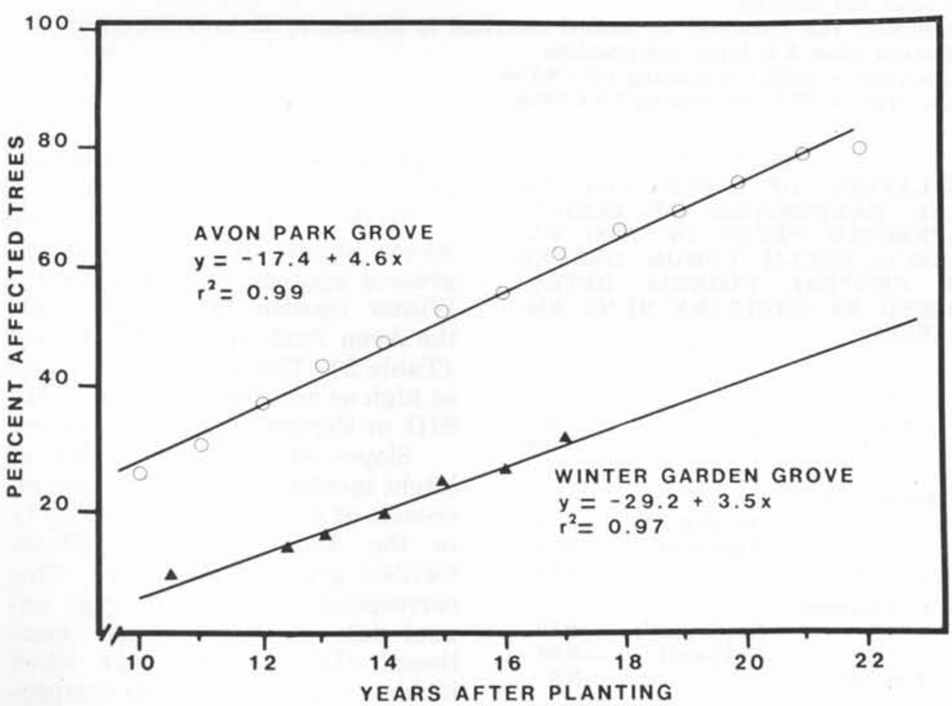

Fig. 1. Relation of blight incidence with time in two 'Valencia'/rough lemon groves in central Florida.

TABLE 4
LINEAR REGRESSION ANALYSIS OF BLIGHT INCREASE DETERMINED IN ANNUAL SURVEYS IN 14 GROVES IN CENTRAL FLORIDA*

Site no.	County	Scion variety	No. trees	Grove age (yr)	Years of data	Affected t_0 - t_f‡ (%)	Avg increase per yr (%)	r^2
1	Lake	Valencia	551	30	6	21.1-33.9	2.1	0.92
2	Lake	Valencia	1583	10	7	1.7-11.8	1.4	0.97
3	Lake	Valencia	775	13	7	4.4-20.1	2.2	0.96
4	Orange	Valencia	1462	19	7	5.0-17.6	1.8	0.94
5	Polk	Valencia	428	29	7	6.1-38.8	4.7	0.97
6	Polk	Hamlin	558	29	7	9.0-49.5	5.8	0.99
7	Polk	Red grapefruit	262	29	6	21.8-39.3	2.9	0.96
8	Polk	Duncan grapefruit	178	30	6	11.2-28.1	2.8	0.90
9	Highland	Valencia	1054	24	5	20.0-50.4	6.1	0.95
10	Highland	Valencia	862	24	7	0.5-17.3	2.4	0.91
11	Highland	Valencia	900	24	7	0.6-19.9	2.8	0.92
12	Highland	Valencia	460	16	6	28.0-49.6	3.6	0.98
13	Highland	Valencia	316	16	6	19.9-35.8	2.6	0.96
14	Highland	Valencia	500	16	6	1.4- 6.2	0.8	0.94

*Incidence data taken from Grimm *et al.* (11).
†All groves were on rough lemon rootstock.
‡t_0 = percentage of blight at first survey; t_f = percentage of blight at final survey.