Relationship Between Incidence and Severity of Banana Leaf Spot in Taiwan

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ABSTRACT

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An epidemic of banana leaf spot was monitored every 2–4 wk for five continuous growing seasons from 1980 through 1985 in 10 locations of southern Taiwan. There was a linear relationship between disease severity (calculated according to Stover's international scale) and incidence (proportion of leaves diseased) when both variates were logarithmically transformed. The slope of the relationship was consistent over the five growing seasons but varied according to location. This variation may reflect an important distinction between disease epidemics in temperate and tropical regions. There was no consistent relationship between the estimated parameter values for the incidence-severity relationship and the overall level of disease (incidence or severity) at each location.

Additional key words: epidemiology, *Mycosphaerella fijiensis* var. *difformis*.

Banana leaf spot (black Sigatoka), caused by *Mycosphaerella fijiensis* var. *difformis* Morelet (7), is an important disease of banana in Taiwan. The disease first appears in early May and becomes severe in the summer season under conditions of high temperature and humidity in southern Taiwan. Field trials have shown that banana yields increase 4–7 kg per bunch, about 18.4–31.7%, when sprayed with fungicides, compared with unsprayed plots (2). Commercial banana plantations receive about 8–10 fungicide applications by aerial or ground spray from July to December each year in attempts to control the disease. The fungicide spray program is determined by monitoring the severity of leaf spot using Stover's international scale method (13).

With this method, the severity of leaf spot is estimated using a percentage scale. To avoid bias in estimating the disease severity, well-trained assessors are needed (13,14.) This method, however, still involves subjective judgment and introduces an error of unknown magnitude, depending on the judgment of different assessors or of the same assessor at different times. In addition, the method is tedious and time consuming. If disease severity can be estimated indirectly from disease incidence data, some of the problems mentioned above may be avoided. If disease incidence is to be used as an indicator for disease severity, then a consistent relationship between the two disease variates must be established for banana leaf spot.

Incidence-severity relationships have been studied for several diseases (4–6,8,9,11,12). These studies, except for coffee rust (8), were done on temperate crops. However, little is known about the incidence-severity relationship in diseases of tropical crops, and the practical use of this relationship has been questioned (4,9).

Although Stover and Dickson (14) demonstrated a direct correlation between average age of the youngest leaf with spots (disease lesions) in an area and the amount of spotting present on an individual banana plant, the relationship between the proportion of leaves infected (disease incidence) and the amount of leaf area spotted (disease severity) of banana leaf spot has not been determined. The purpose of the study described in this paper was to investigate the incidence-severity relationship of banana leaf spot. The study forms part of an extensive research program concerned with the epidemiology and management of this disease in Taiwan.

MATERIALS AND METHODS

Data were collected from commercial banana plantations in southern Taiwan for five seasons from 1980 through 1985. The banana plantations received 8–10 fungicide sprays from July to December every year depending on disease severity and climatic conditions. The same fungicides were used in a cooperative program for aerial spraying. Each plant received 2.0–2.5 kg of fertilizer (22:5.5:11) for the whole growing season. Herbicides were applied as required at recommended commercial rates in early growth stages of banana. Ten sites located at Yuanfu, Chisan, Shichou, Meilong, and Likan, which covered about 4,000 ha of major banana plantations, were selected for analysis (Fig. 1). The site CHEN is located in the far north; LEE is close to a mountainous area at the eastern side; KAN, WEI, and RING are located in the area of confluence of two rivers (Meilong and Nantzu Shein rivers); KUAN, PIN, and PA are along Nantzu Shein River; CHI and TU are located in an open plain; and TU is in the south. The banana plantations are belt-distributed along the river in these areas. The whole area is about 30 km long from south to north and 10 km wide from east to west.

Surveys of banana leaf spot were made every 2–4 wk in each growing season. Ten nonflowered plants were randomly selected in about 1 ha of banana plantation on each occasion in each of the 10 sites for determining disease severity. Disease severity and position of each leaf on the plant were recorded based on Stover's international scale method (13); this scale corresponds to grades of 0 (fewer than 10 spots on an individual leaf), 1 (less than 5% of leaf area spotted), 2 (5–15%), 3 (16–33%), and 4 (more than 33%). Leaves were numbered from the first unfolded leaf downward on each plant. To calculate the amount of leaf area spotted (disease severity, s), the Stover and Dickson scale (14) was modified by using the upper limit of leaf spotted area for disease grades 1, 2, and 3. The equation is:

$$s = (0.05x + 0.15y + 0.35z + 0.5w)/n \qquad (1)$$

in which x, y, z, and w represent the number of leaves with disease grade 1, 2, 3, and 4, respectively; n is the total number of leaves. The proportion of leaves diseased (disease incidence, I) was calculated as the number of diseased leaves divided by the total number of leaves on the plant. After preliminary analysis on each assessment date, the mean disease incidence and severity were calculated for each assessment date at each site as a sampling unit. A total of 768 sampling units were analyzed according to growing season and sites.

All data for the five growing seasons in all 10 sites pooled together and data for each growing season and each site separately were transformed according to standard transformations to achieve the best linear relationship between incidence and severity. The pair of transformations that gave the highest correlation coefficient was then used for regressing incidence on severity for each site and growing season combination (50 regression equations) and to obtain the intercept and slope coefficients. Analysis of variance of the estimates at intercept and slope was then used to compare variation within sites and growing seasons. By this method the variation associated with each coefficient is not carried over into the analysis of variance. In effect, the estimates of slope and intercept are considered as measurements made for each site and year combination. When significantly different ($P = 0.05$), the intercepts or slopes were separated according to Duncan's multiple range test.

RESULTS

There was no consistent trend in the estimated slopes of the incidence-severity relationship for selected times within growing season; all subsequent analyses were made using the mean incidence and severity for each assessment date at each location.

The incidence-severity relationship was curvilinear whether considering data from each growing season and each site separately or all data pooled. Figure 2A shows the incidence-severity relationship for pooled data; there was a greater variance in severity as incidence increased. Severity (s) was transformed according to $\ln(s)$, $\sqrt{s}$, and $\arcsin(s)$; incidence (I) was transformed according to, $\ln(I)$, $-\ln(1-I)$, $\ln(I/(1-I))$, and $\arcsin(I)$. Inspection of the correlation coefficient between pairs of transformed variates showed that $\ln(I)$ and $\ln(s)$ consistently gave the highest coefficients with respect to both separate and pooled data. The incidence-severity relationship for pooled data, after logarithmic transformation of both scales, is shown in Figure 2B.

The general regression equation based on the pooled data was

$$\ln(I) = 0.288 + 0.518 \ln(s) \quad (2)$$

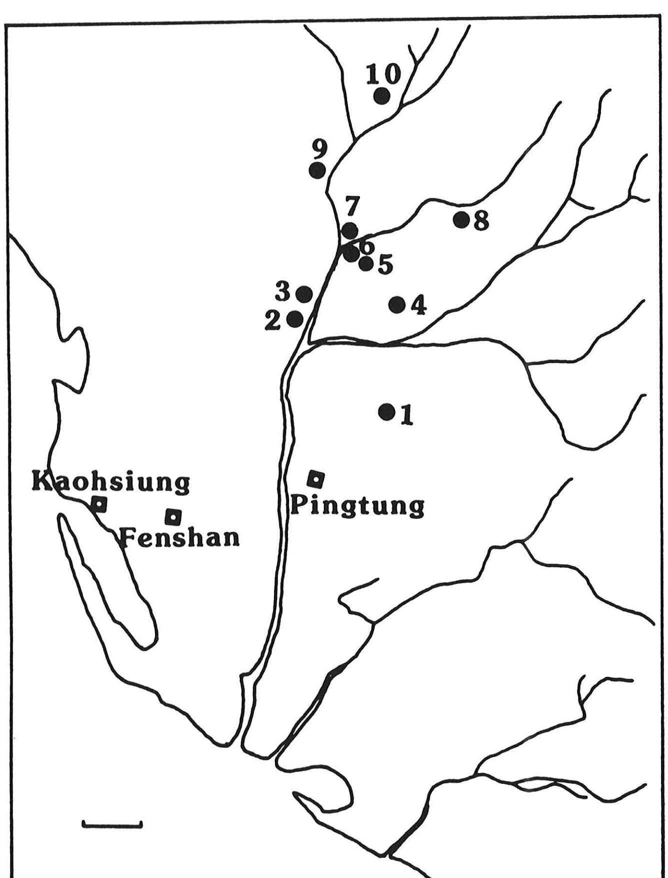

Fig. 1. Map showing the location of banana-growing sites in southern Taiwan. Numbers 1 to 10 represent locations TU, PA, PIN, KUAN, RING, WEI, KAN, CHI, LEE, and CHEN, respectively. (Bar represents 5 km.)

The coefficient of determination (R^2) for this equation was 0.801, with intercept and slope significantly different ($P < 0.001$) from the values 1 and 0, respectively. Parameter estimates for the equations derived for separate growing seasons (over locations) and locations (over growing seasons) are shown in Table 1.

Based on the analysis of variance of the slope and intercept coefficients of the regression lines, the incidence-severity relationship varied according to location (Table 1). The intercepts for KAN, WEI, and RING (positive) were significantly greater than those for CHEN, KUAN, and TU (negative); the intercepts for CHI, LEE, PIN, and PA were intermediate. The slopes for KAN, WEI, and RING were also significantly greater than those for CHEN, KUAN, and TU; the slopes for CHI, LEE, PIN, and PA were again intermediate. The incidence-severity relationship was not affected by the growing season because the mean intercepts and slopes for each growing season were not significantly different.

The back-transformed plots of the equations for each location are shown in Figure 3. All locations showed a faster increase of incidence with increasing severity at low disease levels and a slower increase of incidence with increasing severity at high disease levels. This feature was more noticeable at sites CHEN, KUAN, and TU. The incidence-severity relationships for locations began to diverge at incidence values of about 0.25 (corresponding to severities of about 0.04).

There was no correlation between the slopes (b_1) of the incidence-severity relationship and disease incidence or severity (mean, maximum, or minimum) at each location (Table 2). There were no consistent relationships between the estimates of slope (b_1) and mean disease incidence at each location over the five growing seasons (Fig. 4). There was some geographical basis for the variation in the incidence-severity relationship in southern Taiwan (Fig. 5): The slopes were highest in the area of confluence of the two rivers (KAN, WEI, and RING), and the slopes were lower with distance from these areas. The smallest slopes were at site CHEN in the far north and at site TU in the far south of the banana-growing area.

DISCUSSION

Many studies have evaluated the value of incidence-severity relationships and how these vary from location to location and year to year and are affected by farming practices including cultivar, fungicide treatment, and crop husbandry. Rouse et al (9) studied incidence-severity relationships in wheat powdery mildew.

TABLE 1. Comparison of coefficients from regression lines of the form $\ln(I) = b_0 + b_1 \ln(s)$ for banana leaf spot grouped by location and growing season in southern Taiwan

	Number of Observations	Intercept (b_0)	Slope (b_1)
Location			
KAN	76	0.443 a[z]	0.555 a
WEI	77	0.372 a	0.539 a
RING	76	0.352 a	0.533 a
CHI	77	0.231 ab	0.513 ab
LEE	77	0.184 ab	0.476 abc
PIN	77	0.018 ab	0.453 abc
PA	77	0.009 ab	0.448 abc
KUAN	77	−0.241 b	0.375 bc
CHEN	77	−0.218 b	0.361 c
TU	77	−0.314 b	0.346 c
Growing Season			
1980–1981	128	0.256	0.484
1981–1982	150	−0.024	0.452
1982–1983	170	0.123	0.480
1983–1984	180	−0.005	0.434
1984–1985	140	0.068	0.450

[z] Coefficients for locations followed by the same letter are not significantly different from each other according to Duncan's multiple range test ($P = 0.05$). Coefficients for growing seasons were not significantly different.

Their results differed from the work of James and Shih (5), also with wheat powdery mildew, in that they concluded that incidence might be a poor indicator of severity unless a suitable correction for environmental factors, which may alter the incidence-severity relationship from year to year or from place to place, was made. Both groups of workers found that the incidence-severity relationship of wheat powdery mildew varied with season.

That incidence-severity relationships may vary with season, but not location, has also been demonstrated for wheat leaf rust (5) and apple powdery mildew (11). Seem and Gilpatrick (11) suggested that variability between different seasons had the greatest effect on altering the incidence-severity relationship. Imhoff et al (4) studied incidence-severity relationships of bean rust in epidemics induced in phytotrons and showed that environmental factors might alter the relationship. Our results with black Sigatoka, however, showed that the incidence-severity relationship of banana leaf spot varied with location rather than growing season, where estimates of the slope parameter were remarkably consistent. Our research was conducted in a tropical area, whereas most previous work has been in temperate regions. Tropical ecology is characterized by a stable climate with far less seasonal variation than in temperate regions (3). In addition, the disease assessments by previous workers were made during limited periods of the year, while the disease assessments in our study were made continuously for five growing seasons. From a meteorological standpoint, the 'average' climate may not change too much from year to year in temperate regions, but may be drastically different within short well-defined periods of any given year. This may contribute to the variation in the incidence-severity relationship between growing seasons found by workers in temperate regions, but which are not apparent in our results. If climatic factors play an important role in altering incidence-severity relationships, these should be more consistent for tropical diseases than that for the temperate diseases. More research is required to explore this hypothesis.

Even though the banana-growing area surveyed in this research was relatively concentrated (30 km from north to south), the results showed that the incidence-severity relationship clearly varied with location, if not with growing season. Further, the slope of the transformed incidence-severity relationship was not correlated with incidence or severity at the locations. The biological significance of these findings is that factors affecting disease development varied more within this small geographical area in southern Taiwan than among seasons.

The banana-growing area described in this research is surrounded by mountains in the east and north and is in the area of confluence of two rivers. These geographical factors may result in complex microclimatic changes in the area, although these have not been quantitatively studied. In the senior author's experience, fog occurs often in KAN, WEI, and RING locations and results in high humidities, which may be favorable for disease development. The slopes of the regressions are greater in these locations than others, indicating a more expansive infection of previously healthy leaves (change in incidence) for a given change in mean severity. The banana plantations in PA, PIN, and KUAN are at locations that may be flooded one to several times during summer rainy season. Flood water destroys ascospores produced in the dead leaves on the ground and reduces inoculum (T. Y. Chuang, *unpublished data*). The effects of reduced levels of inoculum may influence the incidence-severity relationships but have not yet been studied. At all locations there may be microclimatic variation that

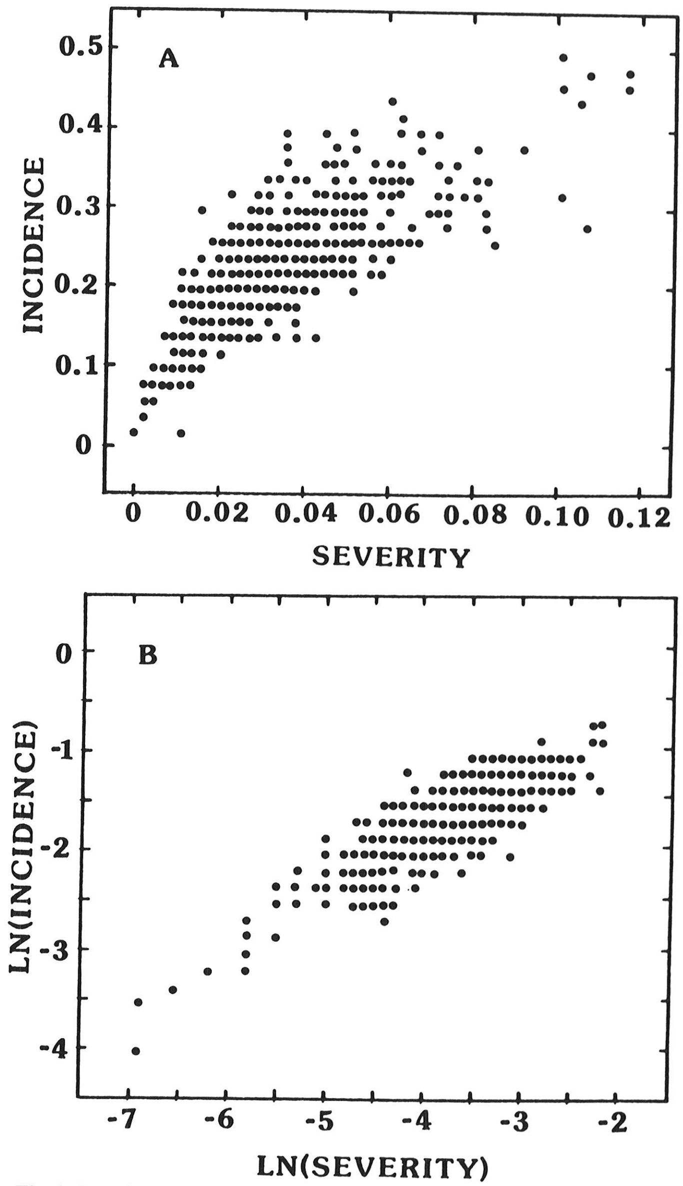

Fig. 2. Relationship between incidence and severity of banana leaf spot; **A,** With untransformed data. **B,** With logarithmic transformation of both axes. Data points shown as (•) represent, in both cases, many hidden observations.

TABLE 2. Comparison of slopes from regression lines of the form $\ln(I) = b_0 + b_1 \ln(s)$ with disease incidence/severity of banana leaf spot at each location in southern Taiwan

		Incidence			Severity		
Location	Slope	Mean	Maximum	Minimum	Mean	Maximum	Minimum
KAN	0.555	0.219	0.481	0.019	0.031	0.116	0.001
WEI	0.539	0.216	0.427	0.028	0.030	0.067	0.001
RING	0.533	0.221	0.454	0.050	0.032	0.116	0.003
CHI	0.513	0.161	0.342	0.042	0.021	0.072	0.002
LEE	0.476	0.214	0.368	0.082	0.028	0.081	0.005
PIN	0.453	0.185	0.383	0.039	0.026	0.107	0.002
PA	0.448	0.211	0.348	0.061	0.032	0.083	0.003
KUAN	0.375	0.203	0.366	0.084	0.028	0.077	0.006
CHEN	0.361	0.268	0.500	0.085	0.047	0.130	0.012
TU	0.346	0.207	0.331	0.093	0.027	0.070	0.005

affects the incidence-severity relationship rather than the overall level of disease.

Fungicide application may affect the incidence-severity relationship (12), although the farmers in this banana-growing area generally participate in a cooperative spray program, which

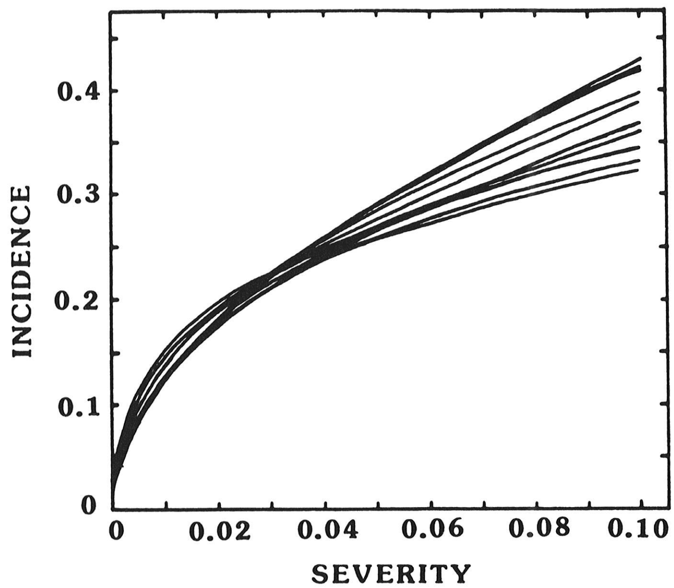

Fig. 3. Relationship between incidence and severity of banana leaf spot at 10 locations in southern Taiwan. Lines represent the fitted regression equations for each location over the 5 yr. Curves from top to bottom represent locations KAN, WEI, RING, LEE, CHI, PIN, PA, CHEN, KUAN, and TU, respectively.

should not vary too much in areas that are close together. Cultural practices used by farmers do vary with different locations; for example, the practice of removing the old, heavily infected leaves by farmers. If heavily infected leaves are removed from the banana trees, then underestimation of disease severity occurs and may result in an alteration of the incidence-severity relationship that is artifactual rather than real. It is difficult to see how these cultural factors could result in the clear geographical variation in slope noted in the study.

If a reliable incidence-severity relationship can be developed, it may be possible to use unskilled labor to record incidence rather than the time-consuming and more demanding severity estimation for banana leaf spot. Our results show that the incidence-severity relationship remained relatively constant under the conditions in Taiwan for a given location. This suggests that the incidence-severity relationship may well be of practical use for assessing leaf spot severity at a given location, which represents, in most cases, the appropriate spatial scale for disease management programs.

Disease incidence and severity relationships were thoroughly reviewed by Seem (10). The relationship can be approached from several standpoints: as representing the stochastic variation inherent in either disease variate at a given point in time; as a consequence of the spatial and temporal dynamics of plant disease epidemics; or as some combination of these two approaches. The first approach has been more commonly taken in disease management studies and methodological questions of sampling design, spatial dimension, and level of replication are of critical importance (10). In this study, the level of replication, 10 trees, was probably too low to establish reliable incidence-severity relationships on any given assessment date and to evaluate how this relationship changes during a growing season. The dynamic aspects of the incidence-severity relationship within a growing season have been less considered. If severity and incidence can both be written as functions of time, then, provided the functions can be

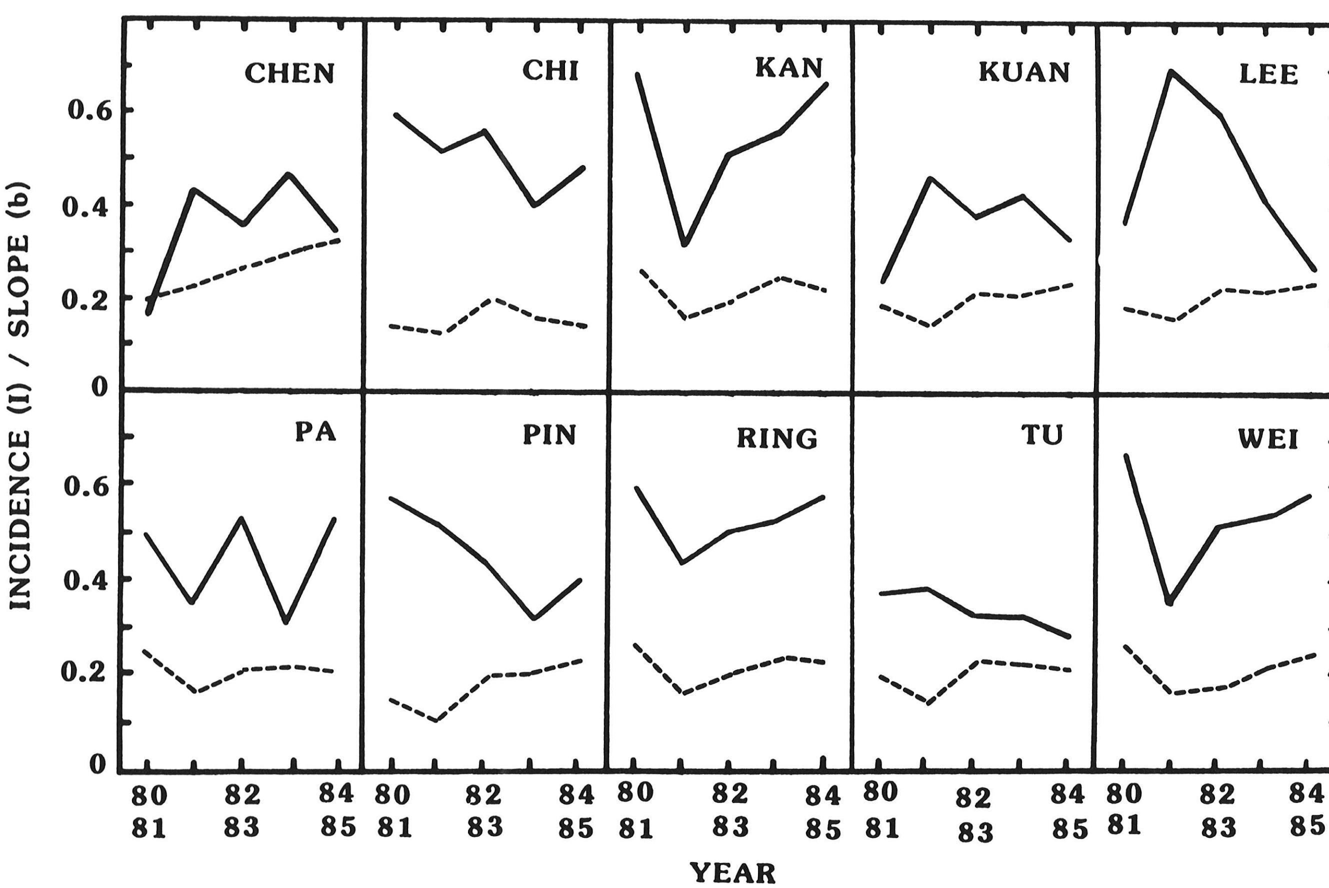

Fig. 4. Mean incidence (I) of banana leaf spot (-----) and slope (b) of the incidence-severity relationship (—) over 5 yr at 10 locations in southern Taiwan. Values on ordinate refer to both incidence and slope parameter.

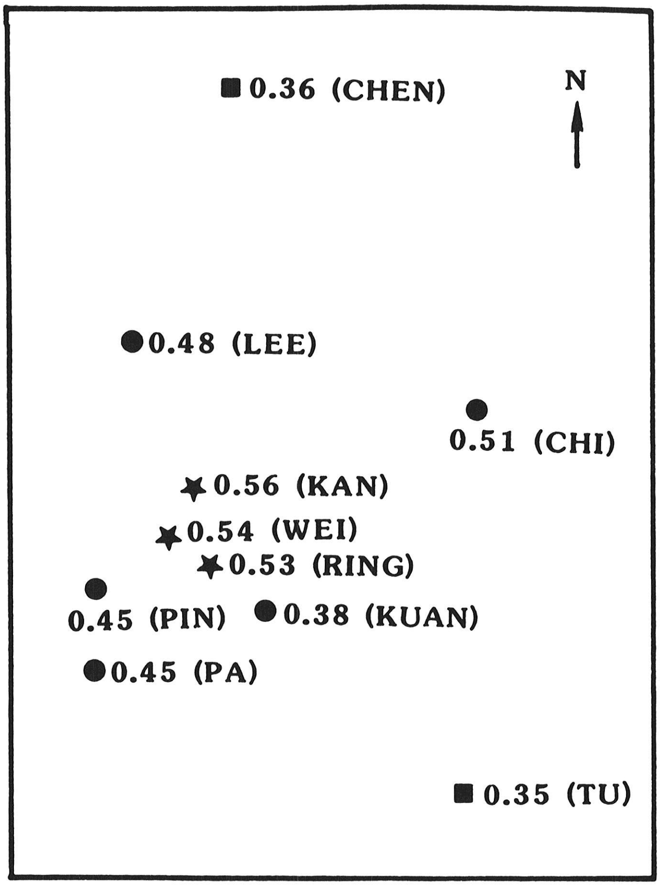

Fig. 5. Map showing the geographical variation in the slope of the incidence-severity relationship of banana leaf spot at locations in southern Taiwan.

inverted, there is a unique relationship between severity and incidence that is independent of time. We take this as one justification for using mean incidence and severity values at different times of the season to derive an overall relationship between incidence and severity. For example, if severity and incidence are increasing exponentially but at different rates during the early stages of an epidemic, then this leads directly to the linear relationship between logarithmically transformed incidence and severity found in this study. The nonlinear version of this equation gives a power relationship of the form $I = \alpha s^{\beta}$. There was no evidence of a trend for severity to lag behind incidence consistently (1).

Theoretically, a sounder approach to deriving dynamic incidence-severity relationships is to derive differential equations linking the rates of change of incidence and severity, as done for example by Waggoner and Rich (15). If this approach can then be combined with elements of stochastic variation then the full epidemiological significance of the incidence-severity relationship, as envisaged by Seem (10), may be realized. Such studies remain a task for the future.

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