Effects of Free Moisture and Soybean Growth Stage on Focus Expansion of Rhizoctonia Aerial Blight

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ABSTRACT

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The effect of free moisture and plant growth stage on focus expansion of soybean aerial blight caused by *Rhizoctonia solani* was quantified with soybeans planted in polyethylene chambers in a greenhouse. An inoculum source was introduced into the chambers at growth stages V2, V5, or V9 and the chambers subjected to free moisture treatments of cycles of 12 hr/day; cycles of 24 hr/day followed by 2 days of 12 hr/day; cycles of 24 hr/day followed by 1 day of 12 hr/day, and 24 hr/day of free moisture. Radius of the focus, number of diseased plants/focus, percentage of leaves diseased, and disease focus severity were measured. Simple linear regressions of the disease variables on days after inoculation showed increases in slopes as free moisture increased. Plant growth stage at inoculation also significantly affected the slopes. Models to predict the development of each disease variable were developed, with accumulated free moisture hours as the predictor. The radius of a disease focus was a linear function of accumulated free moisture hours. Diseased plants/focus and disease incidence were best fitted with equation $Y = 3.142(Bt)^2$, where t is time and B are slopes and were proportional to plant growth stage. Correlation coefficients among disease incidence, focus radius, and diseased plants/focus ranged from 0.885 to 0.96. However, severity of disease foci was less correlated with the other three disease variables. Viability of the tips of aerial mycelia decreased exponentially against period of dryness, with a half-life period of 8.25 days.

Additional keywords: disease modeling, quantitative epidemiology.

Rhizoctonia aerial blight of soybean caused by *Rhizoctonia solani* Kühn is a destructive foliar disease in the tropical and subtropical regions of the world (10,14). In warm and moist seasons, the disease causes severe defoliation and high yield losses (1,6,8,11).

The disease starts at the base of the plants and progresses upward as the mycelium grows. Free moisture is critical to the disease spread (2,8,11,15,17,19). Under humid conditions, mycelial bridges can be readily seen on soybean plants in the field (8,11).

Density of the crop canopy is another important determinant in disease development. Frequent rainfall early in the growing season or before soybean canopy closure did not result in rapid expansion of disease foci in a field with 75-cm row spacing (19). After canopy closure, the disease spreads in a circular pattern as mycelial bridges extend from infected plant parts to noninfected parts of the same plants and adjacent plants (1,8,11,19). Frequent rainfall during late July and August encourages disease outbreaks (19). Singh and Singh (16) reported that reducing row space increased the severity of Rhizoctonia wilt in *Cyamopsis psoralioides*. Joye (8) reported a highly significant correlation between row spacing and soybean defoliation caused by Rhizoctonia aerial blight.

The disease focus is a basic epidemic unit for the quantification of Rhizoctonia aerial blight (19). Therefore, knowledge of how disease foci develop is essential to understanding the population dynamics of aerial blight. The objective of this study was to quantify the effects of free moisture and plant growth stage on the expansion of individual disease foci.

MATERIALS AND METHODS

Plot establishment and inoculation. Experiments were conducted during 1987 and 1988. Soil from a field that had no history of aerial blight was collected and spread to a depth of 30 cm on greenhouse benches. The soil was fumigated on the benches with methyl bromide-12% chloropicrin (MC-2 Dowfume, Dow Chemical Co., Midland, MI) under polyethylene sheets for 10 days. Plots 120 × 120 cm were established on benches by building wooden frames 120 × 120 × 180 cm. Each frame was covered with a clear polyethylene sheet with two removable flaps on opposite sides.

Seeds of soybean cultivar Davis, highly susceptible to aerial blight, were treated with soybean Rhizobium inoculant (Legume Aid, Kalo Inc., Overland Park, KS) and sown in six rows of 120-cm length in each plot with a row spacing of 20 cm. Seedlings were thinned to 26 plants per row after emergence. Planting dates were adjusted to inoculate plants at different growth stages at the same time.

The experimental design was a 4 × 3 factorial with two replications in 1987 and three replications in 1988. The treatments were designed to simulate different free moisture events occurring at different plant growth stages. Four levels of moisture were established as follows: 12-hr free moisture per day at night (12/D), which closely mimicks the pattern of dew occurrence in Louisiana; repeated cycles of 24-hr free moisture followed by 2 days of 12-hr free moisture at night (24-2(12)); repeated cycles of 24-hr free moisture followed by 1 day of 12-hr free moisture at night (24-12); and 24-hr free moisture daily (24/D). Plant growth stages at the beginning of the experiments were V2, V5, and V9 at which the first, fifth, and ninth node at main stem was forming, respectively (4). Treatments were randomly assigned to the moisture chambers.

To create free moisture, a cool-vapor humidifier (Model No. 240, Hankscraft, Gerber Product Company, Reedsburg, WI) was operated inside each chamber. Flow rate of the humidifier was 592 ml of water per hour. Mists in all chambers were controlled by a cycle timer to give a 30-sec mist each 90 sec. In treatments with dry periods, humidifiers were turned off at 9 a.m. and the polyethylene sheets on opposite sides were removed to allow free

moisture on plants to dry rapidly. At 9 p.m., plants were carefully watered from overhead. Then, the humidifiers were turned on and the sheets were replaced again. Temperature in the greenhouse was controlled to maintain chamber temperatures of 25–30 C.

Isolate RS456, *R. solani* anastomosis group 1, intraspecific group IA, was used. An inoculum suspension was prepared by mixing six petri dishes of 2-wk-old colonies of *R. solani* on PDA in a Waring blender with 0.5 L of sterilized water for 30 sec. The inoculum suspension was sprayed onto soybean seedlings at growth stages V2, V5, and V9 in 10-cm-diameter pots simultaneously. Pots were kept in a moisture chamber at 28 C for 36 hr until disease symptoms appeared. Each pot was thinned to six plants with one diseased leaf per plant. One pot was then placed at the center of each chamber containing soybean plants with matching growth stage to provide initial inoculum. The day when the pots were introduced into the plots was considered to be the start of the experiment.

Data collection. In each chamber, radius of disease focus, number of diseased plants/focus, disease incidence (percentage of leaves diseased in the plots), and disease severity in the developing focus (disease focus severity) were measured at 3- to 5-day intervals. The source plants were not counted. During the 20 days of the experiment, leaves on 15 plants at each growth stage were randomly sampled to determine the mean number of leaves per plant. Total leaves per chamber were calculated by multiplying the mean number of leaves/plant by 156 plants/plot. The radius of a focus in a given direction was defined as the distance (cm) from the edge of the source pot to the farthest diseased leaf. Radii in four perpendicular directions were measured, and an average of these four measures was taken as the radius of a focus. Disease incidence was estimated visually if the disease incidence was greater than 20%. If the estimated incidence was less than 20%, diseased leaves were counted and incidence was calculated by dividing the number of diseased leaves by the number of total leaves per plot. Disease severity was defined as the portion of leaf area covered by lesions. Fifteen diseased leaves were randomly selected from the disease focus of a plot to assess disease focus severity.

At the conclusion of each focus expansion experiment, 10 chambers were used to determine the duration of viability of aerial mycelium tips after a no-free-moisture period. The chambers were supplied with free moisture for the first 48 hr to allow aerial mycelium to grow abundantly. No free moisture was supplied for the next 20 sampling days. The sampling intervals in the 1987 experiment were 12 hr for the first 5 days, 24 hr for the next 6 days, and 48 hr for the remaining 8 days. In the 1988 experiment, sampling intervals were 24 hr for the first 12 days and 48 hr for the remaining 8 days. Five aerial mycelial tips, each less than 1 mm long, were taken from each plot and placed on 2% water agar. After incubation at room temperature for 36 hr, viability of each hyphal tip was recorded, if the tip regenerated a new colony. Percent viability was calculated by dividing the number of viable tips by total tips plated for each sampling. A quantitative relationship between aerial mycelium tip viability and no-free-moisture period was analyzed by using an exponential decay equation.

Data analysis. Analysis of variance was used to evaluate the effects of year, replication, growth stage and moisture treatment, day, and the interactions. Four separate error terms were calculated for block (replication), plot (growth stage), subplot (moisture treatment), and repeat measure (day).

To model expansion of focus radius, the radius for jth growth stage (R_j) was taken as a function of time after inoculation. The model used to predict focus radius is:

$$R_j = B_j t \tag{1}$$

in which B_j = rate of advancement of disease focus (cm/unit time) for jth growth stage and t is the time after inoculation. There is no intercept term because R_j is 0 at $t = 0$.

For diseased plants/focus, it was assumed that a disease focus expands in a circular pattern in a uniform crop canopy (8,10). Diseased plants/focus for jth growth stage (D_j) is a function of focus area that can be expressed by:

$$D_j = 3.142(Bt_j)^2 \tag{2a}$$

in which 3.142 is a constant for the area of circle. B_j is a rate parameter (diseased plants/unit time) and t is time after inoculation. Equation 2a was transformed to produce a linear model:

$$(D_j/3.142)^{1/2} = B_j t \tag{2b}$$

Based on the same assumptions for equation 2, the relationship between disease incidence for jth plant growth stage (I_j) and time after inoculation (t) can be expressed as equations 3a and 3b (transformed I_j):

$$I_j = 3.142(B_j t)^2 \tag{3a}$$

$$(I_j/3.142)^{1/2} = B_j t \tag{3b}$$

Progress of disease focus expansion was analyzed in two steps. First, disease progress was examined for each treatment at each growth stage by relating different disease variables (R_j, D_j, I_j) to days after inoculation. Transformed regression models were evaluated based on pattern of the residual plot, F value, $P > F$, and r^2. Regression coefficients were substituted back to the circle equations 2a and 3a to examine the deviation between observed and predicted values (not transformed values). Regression coefficients among different growth stages or moisture treatments were compared. If the confidence intervals ($P = 0.05$) of compared regression coefficients (B) were not overlapped, the two B would be significantly different (9). Because the regression was forced through the origin, r^2 did not equal the percentage of variation determined by the models.

TABLE 1. Analysis of variance F tests and significance ($P > F$) for effect of year, replication (Rep), plant growth stage at inoculation (GS), free moisture treatments (FM), day after inoculation (Day) on disease variables[a]

	Radius		Diseased plants		Incidence		Focus severity	
Source[b]	F	$P > F$	F	$P > F$	F	$P > F$	F	$P > F$
Year	0.04	0.837	0.02	0.899	0.06	0.812	4.25	0.040
Rep	0.75	0.523	0.68	0.568	0.24	0.866	0.13	0.944
GS	23.31	0.001	27.51	0.001	18.57	0.001	6.17	0.002
FM	53.41	0.001	34.00	0.001	24.63	0.001	8.25	0.001
GS × FM	0.04	0.857	0.00	1.000	0.63	0.706	0.86	0.523
Day	118.13	0.001	71.17	0.001	27.71	0.001	33.85	0.001
GS × Day	26.11	0.001	21.10	0.001	9.16	0.001	0.00	1.000
FM × Day	15.90	0.001	12.08	0.001	5.29	0.001	1.56	0.029
GS × FM × Day	0.00	1.000	0.00	1.000	0.00	1.000	0.69	0.854

[a] Radius = distance from edge of source pot to the farthest diseased leaf, diseased plants = number of diseased plants/plot, incidence = percentage of leaves diseased in a plot, and focus severity = percentage of lesion area to leaf area.
[b] Four separate error terms were identified for block (Rep), plot (GS), subplot (FM), and repeat measure (Day).

Second, the relationship between the disease variables and accumulated free moisture hours (M) using data from all moisture treatments was evaluated. The variable M up to tth day after inoculation was calculated as:

$$M_t = \sum_{i=1}^{t} H_i \qquad (4)$$

in which H_i = continuous free moisture hours for ith days. In equations 1–3, M_t was substituted for t.

The relationships among different disease variables were determined by calculating correlation coefficients between the variables for each plant growth stage at inoculation and for the pooled data. All analyses were performed by using the SAS statistical package (12).

RESULTS

Significant differences were not found between years or among replications except for focus severity between the 2 yr (Table 1). As shown by the F values, most variation in disease variables was explained by growth stages at inoculation, moisture treatment, and days after inoculation. The interaction between moisture and growth stage was not significant. The data from the 2 yr were, therefore, pooled for the following analysis.

Progress of disease foci in individual treatment. The expansion of focus radius over time after inoculation was significantly fitted by equation 1 (Fig. 1, Table 2). The regression coefficient (B), which represents the rate of expansion of focus radius, tended to increase as the free moisture or growth stage as inoculation increased. At moisture level 12/D (Fig. 1), B values were less than 0.25 (Table 2) for inoculation at all three growth stages, indicating that the focus radius expanded only slightly under these conditions. For treatments inoculated at stages V2 or V5, the B values at moisture levels 24-2(12) and 24-12 (Fig. 1) were 70 and 50% less (Table 2) than those at continuous free moisture (Fig. 1). However, moisture periods for 24-2(12) and 24-12 were only 50 and 25% less than continuous free moisture (24/D). Significant differences in the effect of growth stage were detected at moisture levels 24-2(12) and 24-12. At 24-2(12), B was 0.327, 0.458, and 1.523 units for treatments inoculated at plant growth stages V2, V5, and V9, respectively. Values of r^2 were less than 0.7 for treatments inoculated at plant growth stages V2 and V5. The r^2 increased as the free moisture or growth stage at inoculation increased. At 24-12, B was 0.939, 0.747, and 2.044 for the treatments inoculated at growth stage V2, V5, V9, respectively. At continuous free moisture (24/D), B for treatments inoculated at

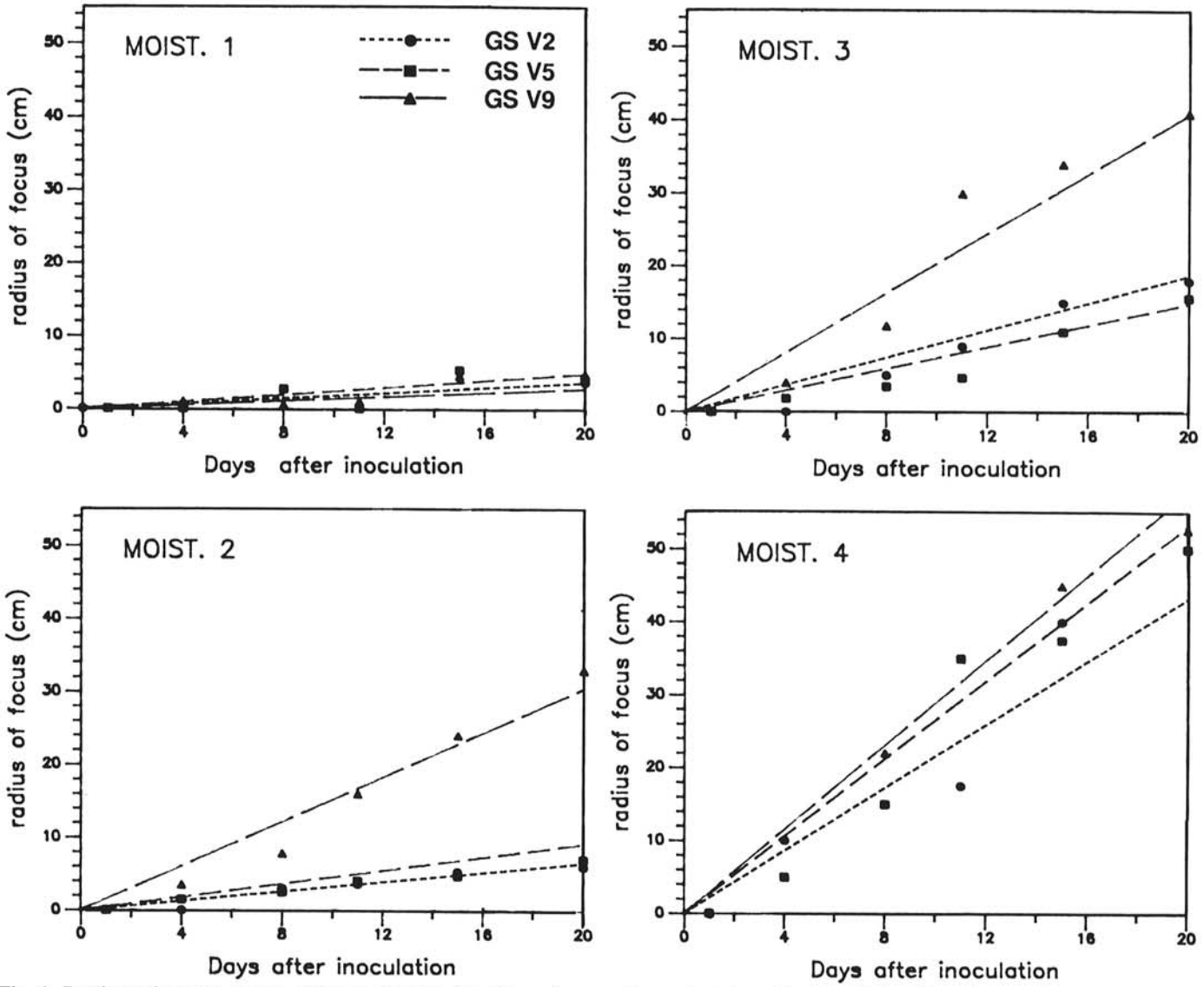

Fig. 1. Predicted lines and means of five replications for disease focus radius against days after inoculation (t) at three soybean growth stages and four free moisture levels (Moist. 1 = cycles of 12 hr/day, Moist. 2 = cycles of 24 hr/day followed by 2 days of 12 hr/day, Moist. 3 = cycles of 24 hr/day followed by 1 day of 12 hr/day. Moist. 4 = cycles of 24 hr/day). Predicting model is $Y = Bt$, where B is cm/day.

the V2 stage was significantly different from those inoculated at V5 and V9.

Diseased plants/focus against days after inoculation were well fitted to the circle equation (Table 2). The residual plots of the transformed version of equation 2 were a random pattern, indicating a normal distribution of model errors. For all treatments, r^2 was greater than 0.88, except for moisture level 24-2(12) at growth stage V5 (Table 2). The r^2 values generally increased as free moisture or plant growth stage at inoculation increased. Like radius expansion, there were differences in the slopes of curves between the treatments inoculated at stage V2 and V5 or V9 under free moisture conditions, 24-12, 24-2(12), and 24/D.

Disease incidence was well described by equation 3 (Fig. 2, Table 2). Residual plots showed random pattern after equation 3b was used. At moisture levels 24-12, 24-2(12), and 24/D, slope (B) for stage V9 was significantly greater than those for stage V2 and V5. Therefore, on day 20, the final disease incidence for treatments inoculated at stage V9 was also significantly higher than treatments inoculated at other stages (Fig. 2). Among different moisture treatments, slopes for 24/D at each inoculation stage were significantly greater than those of other moisture levels at corresponding growth stages (Fig. 2). Values of r^2 were all greater than 0.82 except for one value (Table 2).

TABLE 2. Results of regression of disease focus radius, diseased plants/focus, and disease incidence on days after inoculation (t) for the treatments with different free moisture levels and inoculation at different plant growth stages (GS)

	Free moisture[a]	GS	B	SD[b]	F[c]	r^2
Radius[d]	12/D	V2	0.183	0.037	24.5	0.52
		V5	0.245	0.034	50.67	0.67
		V9	0.141	0.040	12.39	0.39
	24-2(12)	V2	0.327	0.069	22.20	0.54
		V5	0.458	0.057	64.63	0.68
		V9	1.523	0.108	199.91	0.91
	24-12	V2	0.939	0.091	107.50	0.96
		V5	0.747	0.071	110.50	0.85
		V9	2.044	0.093	485.05	0.95
	24/D	V2	2.163	0.133	266.10	0.92
		V5	2.663	0.175	231.80	0.94
		V9	2.837	0.086	1,092.81	0.98
Diseased plants[e]	12/D	V2	0.069	0.007	104.38	0.82
		V5	0.089	0.008	111.87	0.82
		V9	0.110	0.007	240.05	0.93
	24-2(12)	V2	0.098	0.008	156.82	0.89
		V5	0.096	0.010	98.16	0.77
		V9	0.227	0.009	579.06	0.97
	24-12	V2	0.120	0.012	300.64	0.96
		V5	0.149	0.012	148.27	0.89
		V9	0.290	0.012	557.01	0.96
	24/D	V2	0.272	0.012	551.07	0.96
		V5	0.292	0.008	1,318.76	0.99
		V9	0.362	0.008	1,930.26	0.99
Disease incidence[f]	12/D	V2	0.083	0.008	109.66	0.83
		V5	0.065	0.008	74.55	0.75
		V9	0.061	0.003	395.14	0.95
	24-2(12)	V2	0.101	0.101	88.89	0.82
		V5	0.072	0.006	139.38	0.82
		V9	0.136	0.012	128.73	0.87
	24-12	V2	0.092	0.017	99.09	0.87
		V5	0.088	0.006	198.94	0.91
		V9	0.194	0.013	210.88	0.89
	24/D	V2	0.174	0.010	290.14	0.95
		V5	0.209	0.007	832.38	0.97
		V9	0.255	0.007	1,153.56	0.98

[a] 12/D = cycles of 12 hr/day; 24-2(12) = cycles of 24 hr/day followed by 2 days of 12 hr/day; 24-12 = cycles of 24 hr/day followed by 1 day of 12 hr/day; 24/D = continuous free moisture.
[b] Standard deviation of regression coefficient.
[c] All F values were significant at $P < 0.002$.
[d] Model $Y = B^*t$, where Y is the radius of disease focus, B = cm/day.
[e] Model $Y = B^*t$, where Y equals square root of diseased plants/focus divided by 3.142, B = diseased plants/day.
[f] Model $Y = B^*t$, where Y equals square root of disease incidence divided by 3.142, B = unit/day.

The development of disease focus severity appeared not to be a function of time after inoculation. For a diseased leaf, the observed time from symptom occurrence to complete water soaking was only 24 hr if there was continuous free moisture. Therefore, severity of disease foci reached 90–100% 3–4 days after inoculation in the 24/D and 24-12 treatments.

Predicting disease focus expansion using accumulative free moisture hours as a predictor. The model describing focus radius expansion (eq. 1) fit the data well (Table 3) when M was taken as the independent variable (Table 3). Values of r^2 for all three growth stages at inoculation were greater than 0.85. F values were greater than 580 with $P < 0.0001$. All slopes significantly increased as the growth stage increased. Predicted rates of focus expansion were also different between plant growth stages (Fig. 3A).

Diseased plants/focus in relation to M was well described by equation 2 (Table 3). Values of r^2 were all greater than 0.80; F values were also significant ($P < 0.0001$). Residual plots indicated a homogenous variance and random scatter when equation 2b was used. The regression slopes of diseased plants/focus increased with increasing plant growth stage at inoculation (Table 3). Equation 3 also explained most of the variation of disease incidence. F values were significant ($P < 0.0001$) and values of r^2 were greater than 0.75 for the three inoculation stages. Residual plots showed that the transformation was appropriate for fulfilling regression assumptions. The slope of the predicted line for growth stage V9 was greater than those for growth stage V2 and V5 (Table 3). The disease incidence curves showed a trend similar to those of radius of disease focus (Fig. 3A and B).

Relationships among disease variables. The correlation coefficients among focus radius, diseased plants/focus, and disease incidence ranged from 0.87 to 0.96 (Table 4). However, the r value between disease focus severity and other disease variables ranged from 0.283 to 0.583, except for one value (0.717). Similar trends were present in the results for each inoculation stage and pooled data (Table 4).

Viability of aerial mycelium tips (Y) with increasing days of dryness was adequately described by the exponential decay equation, $Y = 84.36 \exp(-0.084t)$ ($r^2 = 0.83$, $P < 0.0001$) (Fig. 4). The model predicted an initial viability level of 84%. The half-life time of the curve was 8.3 days. Even 20 days after stopping free moisture, approximately 20% of aerial mycelial tips were still viable.

DISCUSSION

Outbreaks of aerial blight occur after soybean flowering and fluctuate with the occurrence of rainfall (8,11,19). Yang et al (19) suggested that aerial blight development occurs in two phases. The first phase is before canopy closure and consists of vertical development of disease from soil to plants. The second phase occurs after canopy closure and consists of vertical and horizontal development of disease foci. Our results explain and quantify the influence of free moisture and canopy density on aerial blight development. Expansion of disease foci in treatments inoculated at V9 growth stages was significantly faster than in those at stage V2 or V5 at moisture levels 24-hr/day followed by 2 days 12-hr/day or by one day 12-hr/day, indicating the importance of moisture and leaf-contact to focus expansion. Differences in disease incidence and in number of diseased plants/focus between treatments inoculated at stage V2, V5, and V9 also support the assumption (Tables 2 and 3).

Several workers (8,11,16) reported the association of aerial blight and rainfall. Yang et al (19) considered rainfall frequency and distribution during the growing season as determining factors for an outbreak of aerial blight. In field observations there was no focus expansion during the early growth stages despite heavy rainfalls in one season or during later stages when there was no rain in another season (19). Our experiments mimicking free moisture distribution during the growing season, showed no

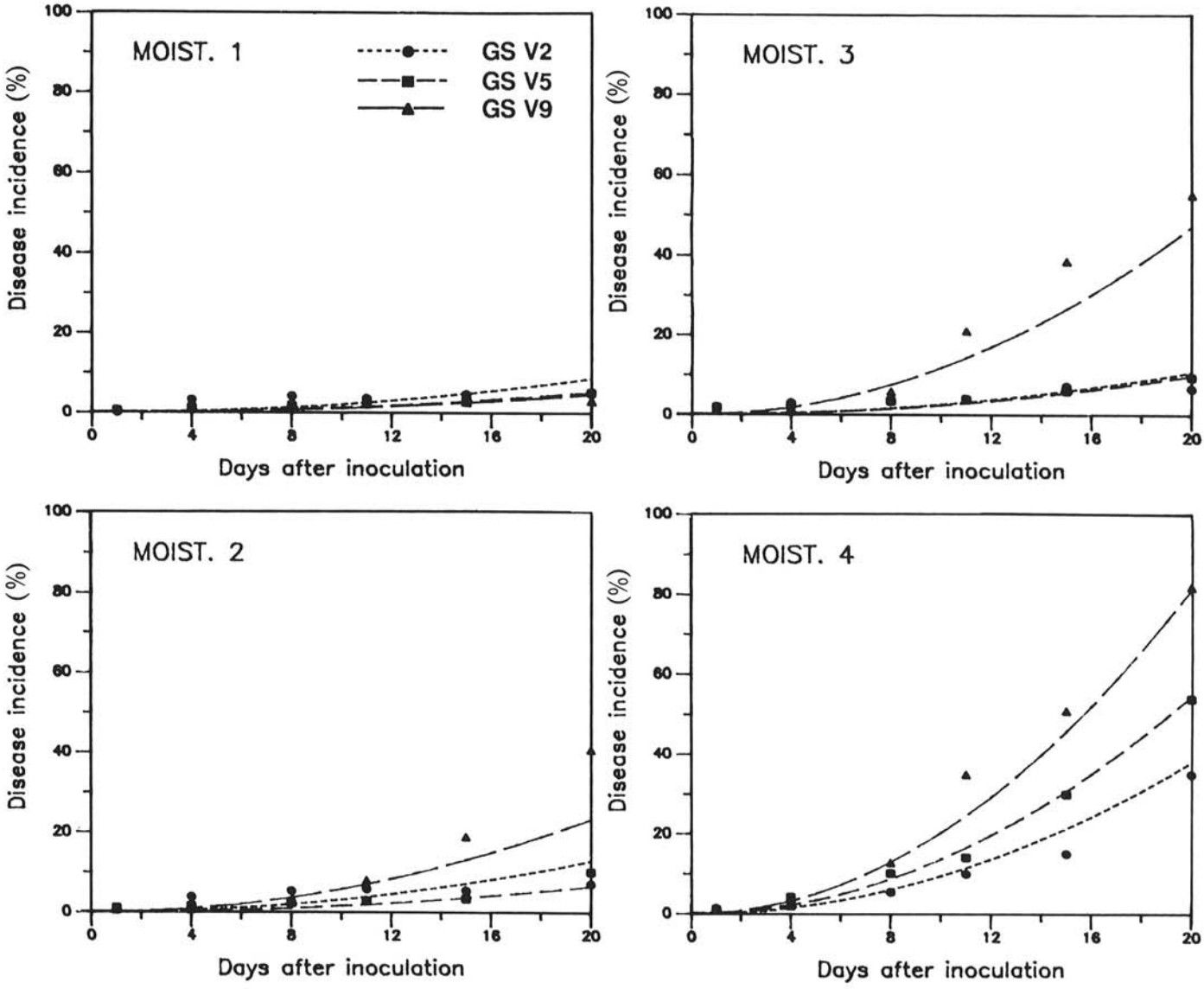

Fig. 2. Predicted lines and means of five replications for disease incidence against days after inoculation (t) at three soybean growth stages and four free moisture levels (Moist. 1 = cycles of 12 hr/day, Moist. 2 = cycles of 24 hr/day followed by 2 days of 12 hr/day, Moist. 3 = cycles of 24 hr/day followed by 1 day of 12 hr/day. Moist. 4 = cycles of 24 hr/day). Predicting model is $Y = 3.142(Bt)^2$, where B is unit of disease incidence per day.

TABLE 3. Regression analysis for disease variables, disease focus radius, diseased plants/focus, and disease incidence in relation to accumulated free moisture hours (M)

Disease variable	Growth stage	B[a]	SD[b]	F[c]	r^2
Radius[d]	V2	0.0900	0.0036	643.4	0.90
	V5	0.1045	0.0040	697.3	0.88
	V9	0.1356	0.0056	581.5	0.86
Diseased plants[e]	V2	0.0116	0.0005	479.9	0.87
	V5	0.0132	0.0007	399.3	0.81
	V9	0.0179	0.0009	422.5	0.82
Disease incidence[f]	V2	0.00781	0.00047	270.9	0.75
	V5	0.00897	0.00056	255.4	0.78
	V9	0.01221	0.00061	406.4	0.82

[a] Regression coefficients with dimension of cm/M, plants/M, and unit/M for corresponding variable.
[b] Standard deviation of regression coefficient.
[c] All F values were significant at $P = 0.0001$.
[d] Model $Y = B^*M$, where Y is the radius of disease focus.
[e] Model $Y = B^*M$, where Y equals square root of diseased plants/focus divided by 3.142.
[f] Model $Y = B^*M$, where Y equals square root of disease incidence divided by 3.142.

disease focus expansion at early growth stages (V2), which had a low canopy density. Disease in plots inoculated at early stages progressed more slowly than those inoculated at later growth stages (Fig. 3A and B). Ikeno (7) reported that *R. solani* requires a certain period of free moisture to complete the infection process on soybean leaves. This may explain the lack of focus expansion in the treatments with only 12-hr of daily free moisture (Figs. 1 and 2). The occurrence of dry periods during the growing season may also delay the expansion of disease foci by reducing the viability of aerial mycelium (Fig. 4). Schneider (13) reported a 50% decrease of growth rate for *R. solani* at 99% RH compared with 100% RH. The threshold value for mycelium growth was 95% RH (13). An incorporation of aerial mycelium viability into disease focus expansion models may improve prediction.

In a study of 86 isolates of *R. solani*, Durbin (3) found that aerial blight isolates had mycelium growth rates ranging from 20 to 37 mm/day, with a mean of 28 mm/day. In our study, the rate of focus radius expansion was 22–28 mm/day in continuous free moisture treatments, which is consistent with Durbin's data.

Models developed fit the data well. Though the models were forced through the origin, values of r^2 in these models were still an approximate reflection of percent variation determined by the

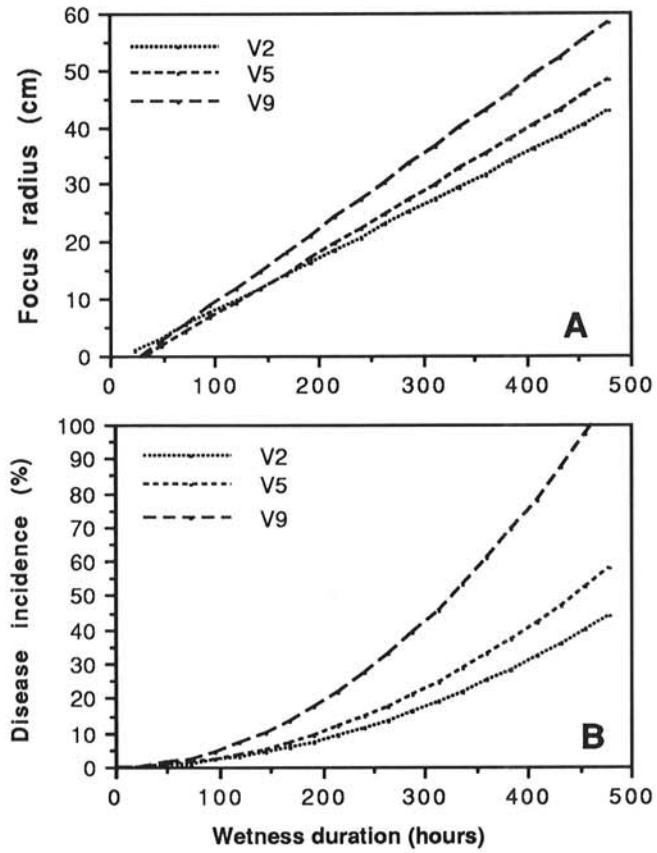

Fig. 3. Prediction of disease focus radius (A) with $Y = BM$ and disease incidence (B) with $Y = 3.142(BM)^2$ against wetness duration after inoculation (M) at soybean growth stages V2, V5, and V9, respectively. B is regression coefficient given in Table 3.

TABLE 4. Correlation coefficients[a] among disease variables[b] following inoculation with *Rhizoctonia solani* at plant growth stages V2, V5, and V9 and for pooled data from all three stages

Growth stage	Radius	Diseased plants	Incidence	Focus severity
V2				
Radius	1.000	0.942	0.909	0.465
Diseased plants		1.000	0.962	0.396
Incidence			1.000	0.388
Severity				1.000
V5				
Radius	1.000	0.963	0.939	0.346
Diseased plants		1.000	0.961	0.303
Incidence			1.000	0.283
Severity				1.000
V9				
Radius	1.000	0.927	0.894	0.717
Diseased plants		1.000	0.962	0.583
Incidence			1.000	0.570
Severity				1.000
Combined				
Radius	1.000	0.925	0.875	0.522
Diseased plants		1.000	0.961	0.445
Incidence			1.000	0.415
Severity				1.000

[a] All correlation coefficients were significant at $P = 0.0001$.
[b] Radius = the distance from edge of source pot to the farthest diseased leaf, diseased plants = number of diseased plants/plot, incidence = percentage of diseased leaves to total leaves in a plot, and focus severity = percentage of lesion area to leaf area.

model because insignificant intercepts would not have much effect on the bias of the coefficient of determination. Some modifications may be necessary when models are applied as disease development components to field conditions because focus expansion in the greenhouse may differ from that in the field. O'Neill et al (11) reported that in drill-seeded or broadcast soybean, aerial blight typically spread in a circular pattern, but in fields with row-planted soybeans, disease spread down the row first. In our experiment, the narrow row spacing provided a uniform canopy that was similar only to what occurs in broadcast or drill-seeded soybean. Furthermore, the effects of wind on the spread of disease focus expansion needs further investigation. Prediction of aerial blight development in a field also requires information concerning the distribution of initial disease foci in the field (18).

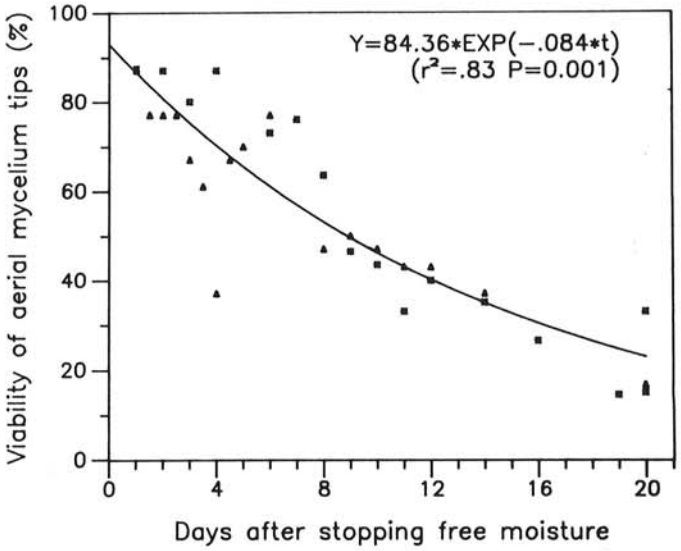

Fig. 4. Viability of aerial mycelium tips in relation to days after free moisture for 1987 (triangle) and 1988 (square).

Value of correlation coefficients indicated that the disease variables can be classified into two groups (Table 4). Focus severity alone fell in one group and may not be suitable for the description of temporal disease development. Another group consists of focus radius, diseased plants/focus, and disease incidence. They were inherently correlated as shown by the derivation of equations 1–3 and any of them can be used to describe the disease-time relationship.

LITERATURE CITED

1. Atkins, J. G., and Lewis, W. D. 1954. Rhizoctonia aerial blight of soybean in Louisiana. Phytopathology 44:215-218.
2. Baker, R., and Martinson, C. A. 1970. Epidemiology of disease caused by *Rhizoctonia solani*. Pages 179-188 in: *Rhizoctonia solani*: Biology and Physiology. J. R. Parmeter Jr., ed. University of California Press, Berkeley.
3. Durbin, R. D. 1959. Factors affecting the vertical distribution of *Rhizoctonia solani* with reference to CO_2 concentration. Am. J. Bot. 46:22-25.
4. Fehr, W. R., Caviness, C. E., Burmond, D. T., and Pennington, J. S. 1971. Stage of development descriptions for soybean, *Glycine max* (L.) Merrill. Crop Sci. 11:929-931.
5. Galindo, J. J., Abawi, G. B., Thurston, H. D., and Galvez, G. 1983. Source of inoculum and development of bean web blight in Costa Rica. Plant Dis. 67:1016-1021.
6. Hepperly, P. R., Mignucci, J. S., Sinclair, J. B., Smith, R. S., and Judy, W. H. 1982. Rhizoctonia web blight of soybean in Puerto Rico. Plant Dis. 60:256-257.
7. Ikeno, S. 1933. Studies on sclerotium diseases of the rice plant. VIII. On the relation of temperature and period of continuous wetting to the infection of soybean by the sclerotia of *Hypochnus sasakii* Shirai and on autolysis of the same fungus. Forsch. Geb. Pflanzenfrankh. Kyoto 2:238-256.
8. Joye, G. F. 1986. Management of Rhizoctonia aerial blight of soybean and biology of sclerotia of *Rhizoctonia solani* Kühn. Ph.D. thesis. Louisiana State University, Baton Rouge. 91 pp.
9. Kleinbaum, D. G., Kupper, L. L., and Muller, K. E. 1988. Applied Regression Analysis and Other Multivariable Methods. 2nd Ed. PWS-KENT Publishing Company, Boston. 718 pp.

10. Ogoshi, A. 1987. Ecology and pathogenicity of anastomosis and intraspecific groups of *Rhizoctonia solani* Kühn. Annu. Rev. Phytopathol. 25:125-143.
11. O'Neill, N. R., Rush, M. C., Horn, N. L., and Carver, R. B. 1977. Aerial blight of soybean caused by *Rhizoctonia solani*. Plant Dis. Rep. 61:713-717.
12. SAS Institute. 1985. SAS User's Guide: Statistics, Version 5 Edition. SAS Institute Inc. Cary, NC. 956 pp.
13. Schneider, R. 1953. Untersuchungen uber Feuchtigkeitsanspruche parasitischer Pilze. Phytopathol. Z. 21:63-78.
14. Sinclair, J. B., and Backman, P. A. 1989. Compendium of Soybean Diseases. 3rd ed. The American Phytopathological Socity, St. Paul, MN. 106 pp.
15. Singh, R., Shukla, T. N., Dwivedi, R. P., Shukla, H. P., and Singh, P. N. 1974. Study on soybean blight caused by *Rhizoctonia solani*. Ind. J. Mycol. Plant Pathol. 4:101-103.
16. Singh, R. S., and Singh, B. 1955. Root rot and wilt of *Cyamopsis psoralioides* in relation to thick and thin sowing of the crop. Agra Univ. India J. Res. Sci. 4:379-385.
17. Wu, Lung-chi, and Lin, Yi-shan 1966. Rhizoctonia aerial blight of soybean caused by *Thanatephorus cucumeris*. Mem. Coll. Agric. National Taiwan University 9:57-69.
18. Yang, X. B. 1989. Ecology and epidemiology of Rhizoctonia foliar blights of soybean. Ph.D. thesis. Louisiana State University, Baton Rouge. 157 pp.
19. Yang, X. B., Snow, J. P., and Berggren, G. T. 1990. Analysis of epidemics of Rhizoctonia aerial blight of soybean in Louisiana. Phytopathology 80:386-392.