CSGR-1: A Computer Simulator of Groundnut Rust[1]

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ABSTRACT

A computer simulator of groundnut rust (*Puccinia arachidis* Speg.), CSGR-1, was constructed based on four mathematical submodels describing environmental effects on (1) the increase rate of disease severity and daily multiplication factor of diseased leaflets, (2) the relationship between host growth and the effective accumulated temperatures, and (3) the relationships between infectious tissue and disease severity. The simulator was validated using independent data sets. With CSGR-1, disease development of groundnut rust can be predicted eleven days in advance given appropriate climatic data.

Key Words: *Puccinia arachidis* Speg. *Arachis hypogaea* L. peanut, epidemiology, computer simulation.

Since the construction of EPIDEM in 1969 (10), many computer simulators of plant disease have been constructed which play an important role in disease management research. These simulators are based on detailed studies of various stages of the pathogen lifecycle (10,11,12).

Groundnut rust (*Puccinia arachidis* Speg.) is one of the most limiting constraints to groundnut production in the world by causing great yield loss (5,7,12,13,15,16). In the past, the epidemiological studies of the disease consisted only of the descriptions of ecological factors, disease progress curves and disease forecasting with multiple regression equation (5,12,13,15,16,17). No computer simulator of the disease could be found in the literature.

The objective of the present study was to develop a computer simulator for the disease based on several important parameters, including effects of climatic conditions on increase rates of disease incidence and severity, growth and defoliation of the host, and the relationship between infectious tissue and total diseased tissue.

Materials and Methods

The field experiments were conducted on the farm of the South China Agricultural University in Guangzhou, Guangdong Province. The groundnut cultivar was Yeyou 551-116 (Guangdong Oil 551-116), the major cultivar grown in South China. The study was based on the results of experiments conducted from August to December, 1982, and March to July, 1983. Two seeds per hole were hand-sown to a depth of about 2 cm in rows about 22 cm apart, with a 10 cm spacing between holes. The resulting population was approximately 300,000 plants per hectare. All fields were rice paddy areas with rice as the previous crop, as groundnut is commonly rotated with rice in South China. All plots were raised beds, averaging 1.5 m in width, separated by 35 cm furrows. The experiment field was approximately 0.1 hectare in size and was divided into 5 plots. All cultivation methods were the same as those for commercial practice (1).

DISEASE ASSESSMENT: After the initial appearance of rust, observations were made in all plots every 2 to 4 days. Disease assessments were conducted on 10 randomly selected plants in each plot. On each plant only the main stem was assessed. The disease severity was based on grades of infection (12) of each leaflet, and the rate of defoliation of the main stem was based on the number of leaflets missing.

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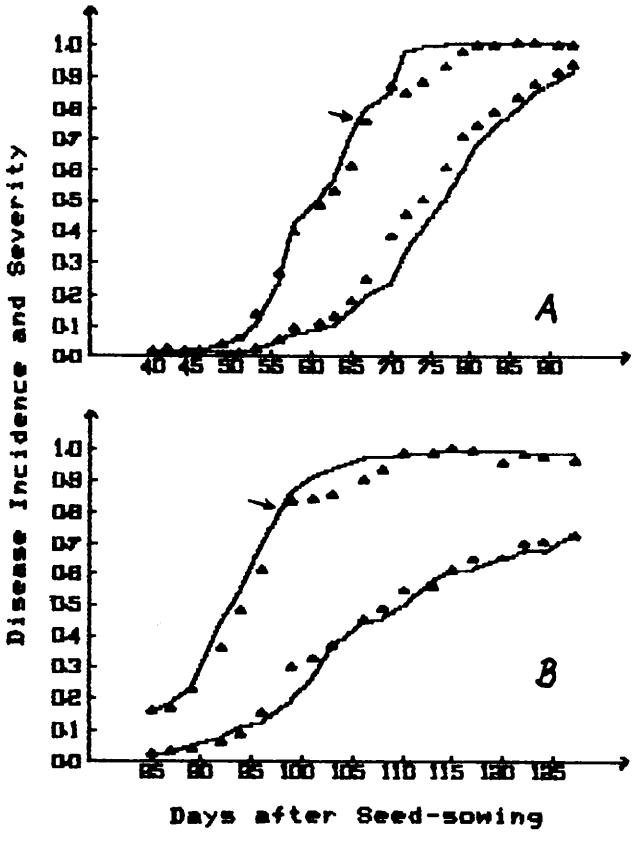

Fig. 1. Comparisons between disease development curves based on observed progress values (triangle) and simulated ones with CSGR-1. The upper curve (with an arrow) is disease incidence and the lower one disease severity for each graph.
A: Experiment in autumn, 1982.
B: Experiment in spring, 1983.

Disease incidence and severity were calculated for each observed plant, and the mean values were used for each assessment.

In the present study, disease incidence was defined as the proportion of diseased leaflets to total leaflets, and disease severity (ST) was calculated as follows:

$$ST = \sum_{i=1}^{7} i \bullet N_i/(7N)$$

in which, N_i is the number of leaflets of grade i, N is the number of total leaflets, and 7 is the maximum disease grade (12).

Meteorological data was provided by Guangzhou Weather Station, 3 km from the University farm test site, including daily maximum, average and minimum temperatures (Tmax, T and Tmin, C), average and minimum relative humidity (RH and RHmin, %), daily average wind speed (WS, meters per second), daily radiation intensity (RAD, calories per square centimeter), etc.

DATA ANALYSIS AND ESTABLISHMENT OF SUBMODELS

SUBMODEL I – LOGISTIC INCREASE RATE OF DISEASE SEVERITY: Vanderplank (9) formulated the apparent infection rate (r) as follows:

$$r = (\ln[X_2/(1-X_2)]-\ln[X_1/(1-X_1)])/(t_2-t_1) \quad (1)$$

in which, X_1 and X_2 are disease proportion at time t_1 and t_2, respectively.

Usually the r value is not constant during disease progress, and will vary with factors such as climatic conditions, growth stages of host, amount and aggressiveness of inoculum, etc. (19). Because in equation (1) no host factor is involved, and sometimes negative r values are obtained, Kushalappa and Ludwig (4) proposed another equation as follows:

$$p'' = \ln(X_2(1-MX_1)/[MX_1(1-X_2)])/(t_2-t_1) \quad (2)$$

in which M = Y1/Y2, Y1 and Y2 are host populations (number of total leaflets) at time t_1 and t_2 respectively.

As mentioned above, the apparent infection rate is a function of climatic conditions, host, and pathogen, providing a quantitative assessment of such influencing factors (19). The submodel I was intended to describe the interaction between such factors and the increase rate of disease severity.

Forty-three p" values were calculated between two successive X_1 values for equation (2). It is known that p" is based on the total infected tissue (4), but the assessments of p" could only be made on those that passed beyond the latent period. It was assumed in the present study that the diseased tissues visable were those infected one latent period earlier. According to the length of incubation period of the disease (6) and based on the fact that the latent period is longer than the incubation period, it was postulated that the difference in disease level between two successive observations was mainly a result of the infections nine to thirteen days earlier. Stepwise multiple regression analysis (SMRA) showed that a period of ten to twelve days earlier gave the best result.

SMRA was performed to evaluate the relationship of various factors to apparent infection rate p", the result showed that equation (3) was the best model to describe such relationship with high F value and high coefficient of determination (R^2).

$$p'' = 5.3147 - 1.8422X_1 + 0.2193X_2 - 0.049X_3 + 0.1973X_4 - 2.5041X_5 + 1.8508X_6 - 0.02046X_7 \quad (3)$$

in which, $X_1 = \ln(RH)^*$, $X_2 = \ln^2(RHmin)$, $X_3 = \ln(WS)$, $X_4 = \ln(RAD)$, $X_5 = \ln(Tave)$, $X_6 = \ln(Tmax)$, $X_7 = \ln(S5$, 10 days prior to $t_1)$

S5 for X_7 was calculated by equation (9) in submodel IV.

The coefficient of determination and F value for the submodel were $R^2 = 0.579$, $F = 5.87$ ($F_{0.001} = 4.82$ for n = 43).

SUBMODEL II – RELATIVE INCREASE RATE OF INFECTED LEAFLETS: The relative increase rate of infected leaflets (R) refers to the daily multiplication factor of infected leaflets.

$$DL = TL - FL - HL$$

$$R = (DL_2 - DL_1)/DL_1/(t_2 - t_1)$$

in which DL_1 and DL_2 were infected leaflets at t_1 and t_2, TL, FL and HL were total, fallen and healthy leaflets, respectively. (4)

Due to the same reason mentioned for submodel I, this submodel was also constructed with the climatic conditions ten to twelve days prior to t_1.

SMRA was performed to select the most appropriate equation which is shown below:

$$R = \exp(-8.949\times10^{-5}X_1 + 14.5264X_2 - 0.8192X_3 + 8.675X_4 - 1.2777\times10^{-15}X_5 + 0.9482X_6 - 75.2739)$$

in which $X_1 = (RH)^4$, $X_2 = \ln(RHmin)$, $X_3 = \ln(WS)$, $X_4 = \ln[\ln(RAD)]$, $X_5 = \exp(Tmax)$, $X_6 = \ln$ (Healthy leaflets ten days prior to t_1).

The coefficient of determination and F value for this submodel were $R^2 = 0.781$ and $F = 19.07$ ($F_{0.001} = 5.12$ for n = 37).

SUBMODEL III - HOST GROWTH: Plant disease develops within a host population. The host itself also grows with time during a growing season, thus affecting the apparent increase of disease both by providing new infection sites and by proportionally reducing disease level relative to healthy tissue (9). The growth of the host plant is, therefore, also an important factor which must not be ignored (18).

A submodel to simulate groundnut growth was constructed which described the relationship of effective accumulated temperatures, ST to (a) the growth rate of total leaflets and (b) the defoliation rate of leaflets. ST was calculated by the following equation:

$$ST_j = \sum_{i=1}^{j} (T_i - BZ) \quad (5)$$

in which, ST_j is the effective accumulated temperatures on jth day after seed sowing, Ti daily average temperature on ith day after seed sowing, and BZ is the biological zero degree, the minimum temperature for groundnut growth, which is 12 C in this case (1).

It is known that the defoliation of a groundnut plant may be due to either physiological or pathological causes, but in the present study, defoliation was defined only as that caused by physiological effects, because the defoliation caused by pathological effects was envolved in the disease severity. During field observations, only the fallen leaflets with a disease grade 3 or less (12) were classified as physiological defoliation. With data recorded in the field, total leaflets, TL, and fallen leaflets, FL, per plant were calculated.

The rate of the increase of new leaflets on a plant is greatly affected by the number and condition of the old leaflets, which provide materials for growth through photosynthesis. Thus the rate of growth is a function of the old leaflets; because there is an upper limit for population growth of the leaflets, the relative increase rate will decrease as the population of old leaflets increase. Providing the relative increase rate is (a - bN), we have:

$$dN/dt = N(a - bN) \quad (6)$$

in which N is the number of old leaflets and t the time.

*Unless otherwise stated, the climatic conditions incorporated in submodels I and II were the mean values on ten to twelve days prior to t_1.

Table 1. Calculated Values of the Parameters of the Dynamic Equations of Growth and Defoliation of Groundnut Plant*.

	Crop	a	r	R^2	F value	$F_{0.001}$	K
Growth	Spring	-15.0745	2.3984	0.9517	173.08	15.38	73.29
	Autumn	-21.1656	3.3606	0.9409	366.20	14.19	82.00
Defoliation	Spring	-33.1642	4.9582	0.8828	135.55	15.38	28.65
	Autumn	-25.8623	3.9893	0.8874	190.99	14.19	28.00

*Linear Transformation Y=ln[X/(K-N)]; T=ln(ST);
the Equation is Y = a + r T
r and a are the slope and intercept of the linear equation, respectively.

This is the well-known logistic equation for the growth of a population. Let k = a/b, r = a, then

$$dN/dt = r N (1 - N/K) \quad (7)$$

in which r is the intrinsic rate of natural increase, K is the environmental carrying capacity, and N the population size at time t. In the present study, the K value of the leaflets increase in a plant was estimated by using Wang and Lin's "Two-paired Points Method" (14).

From equation (7)

$$\ln[N/(K-N)] = rt + a \quad (8)$$

It is generally known that the growth and defoliation of a plant have a closer relationship with ST than with the time t. So we can develop the submodel for relationship of plant growth with ST instead of t. As defoliation is a growth stage, the above equation is also used to describe the defoliation process.

Comparing equation (8) with some other functions giving the same curve type showed that equation (8) with t changed to ln(ST) is the best equation for describing host growth and defoliation giving the highest R^2. The parameters of the submodel are shown in Table 1.

SUBMODEL IV - RELATIONSHIP BETWEEN INFECTIOUS TISSUE AND INFECTED TISSUE: The feedback of infectious tissue to disease development is important information in an epidemiological simulator (18). Submodel I shows that the diseased leaflets of grade 5 or less have a significant effect on the increase rate of disease severity. Such leaflets were considered as infectious tissues. In order to relate the calculation of infectious tissue to disease severity, the following equation was incorporated into the model.

$$S5 = \sum_{i=1}^{5} i \cdot N_i/7 \quad (9)$$

in which, N_i is the number of leaflets of grade i, N the number of leaflets, 7 the maximum disease grade (12). S5 is defined as infectious tissue in the submodel.

With data obtained, a curve describing the relationship between S5 and S7 was plotted having an asymmetrical distribution with a peak. If S5/ST was plotted against S7, a decrease curve was obtained. Therefore, a function was derived for the relationship between S5 and S7 as follows:

$$S5 = ST \ln(A - B\ S5) \quad (10)$$

Using least square method, the parameters A and B were computed as 2.774 and 1.8297, respectively. The coefficient of determination and F value for the equation were $R^2 = 0.983$ and $F = 2475.7$ ($F_{0.001} = 12.16$ for n = 45).

ESTABLISHMENT OF CSGR-1

A model CSGR-1 (a Computer Simulator of Groundnut Rust, Number 1) was established by incorporating all the submodels mentioned above according to the disease dynamics. The solution interval (18) of CSGR-1 is one day.

CSGR-1 is expected to forecast disease development eleven days in advance. The initial data to be incorporated are: starting day and ending day for simulation (number of days after seed-sowing), disease incidence and severity in the first assessment, effective accumulated temperatures between seed-sowing and simulation starting day, plant season (spring or autumn), and daily climatic conditions involved in the four submodels.

VALIDATION OF CSGR-1

It is desirable when creating a simulator to perform a validation test using data not used in the establishment of the model (3,8). Ten data sets obtained from 1978 to 1983 and not involved in constructing the model were used to validate CSGR-1. Linear regression was made of the simulated disease level (Y) and the observed one (X); an equation, Y=a+bX, was obtained. Obviously, if a=O and b=1, the disease development simulated is the same as that observed. Statistical test (t test) for a=O and b=1 (8) was made. The mean degree of simulation accuracy (P) was calculated by the following equation (15):

$$P = [1 - abs(X - Y)/X] \times 100 \quad (11)$$

Table 2. Validation Test of CSGR-1

Season[1]	Item[2]	N[3]	R	a	t(a)	b	t(b)	P	t(.05)
1978.S	INC	7	0.9910	-0.0183	0.37	1.1971	2.72	86	2.45
1979.S	INC	5	0.9697	-0.1127	1.12	1.3462	1.76	86	2.78
1980.S	INC	6	0.9759	-0.0167	0.18	1.0563	0.48	95	2.57
1982.S	INC	11	0.9649	0.0012	0.02	1.0759	0.78	92	2.23
1983.S	INC	19	0.9816	0.1618	4.95	0.8632	3.36	84	2.10
1978.A	INC	5	0.9787	-0.0752	0.79	1.2425	1.61	90	2.78
1979.A	INC	8	0.9649	-0.1071	1.11	1.1430	1.13	84	2.37
1980.A	INC	8	0.9917	-0.0168	0.49	1.0617	1.10	89	2.37
1981.A	INC	5	0.9773	0.0557	0.59	0.8649	1.25	94	2.78
1982.A	INC	24	0.9955	0.0018	0.13	1.0362	1.73	90	2.07
TOTAL	INC	98	0.9762	0.0107	0.62	1.0383	1.63	89	1.99
1978.S	SEV	7	0.9893	-0.0389	1.09	1.7257	6.38	61	2.45
1979.S	SEV	5	0.9904	-0.0364	1.84	1.3668	3.33	86	2.78
1980.S	SEV	6	0.9939	-0.0097	0.31	1.1131	1.83	89	2.57
1982.S	SEV	11	0.9816	-0.0099	0.36	1.1425	1.92	89	2.23
1983.S	SEV	19	0.9924	-0.0044	0.32	0.9804	0.66	88	2.10
1978.A	SEV	5	0.8684	-0.0481	0.40	1.3861	0.84	75	2.78
1979.A	SEV	8	0.9919	-0.0279	1.42	1.2009	3.20	79	2.37
1980.A	SEV	8	0.9946	-0.0272	1.39	1.3161	5.64	79	2.37
1981.A	SEV	5	0.9995	-0.0037	0.46	0.9995	0.03	99	2.78
1982.A	SEV	24	0.9932	-0.0162	1.40	0.9431	2.42	78	2.07
TOTAL	SEV	98	0.9611	0.0038	0.30	1.0310	1.03	82	1.99

1) S:Spring, A:Autumn
2) INC:incidence, SEV:severity
3) N:the number of data-pair

Results (Table 2) showed that in some cases there was difference found between a and O or b and 1; however, in total test for incidence and severity, there was no significant difference. The simulation accuracy showed that the disease development is very close to that observed. The correlation coefficient (R) showed that there was a very significant correlationship between Y and X. Two validation tests were shown in Fig. 1.

Discussion and Conclusion

In the present study, the logistic increase rate of disease severity was used as a parameter to be incorporated into the computer simulator of groundnut rust, CSGR-1. The results of the validation test of the model showed a reasonably precise description of the disease progress.

The data for establishment of CSGR-1 were obtained directly from experiments in fields. The infection process was simplified to a certain extent. Such method of simulation is different from those in which the study is based on the lifecycle of the pathogen (2,10,11,18). However, due to its simplicity, a micro-computer with fairly small memory capacity is adequate for the simulation task and the model can be easily used by commercial groundnut producers. The simulator, CSGR-1, is expected to forecast disease development eleven days in advance. But, as is often the case, CSGR-1 sometimes experiences some deviation from disease development.

The validation of CSGR-1 with several data sets might not be enough to discover some possibly existing weak points in the model, further tests with more data or even further studies are therefore needed to improve and test the model for practical applications, and, of course, the model itself needs to be improved while applied.

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