Jour. Ind. Soc. Ag. Statistics
51(2&3), 1998 : 293-302

Modelling Progress of Fungal Attack on Groundnut

C.D. Mayee, Anita Shah[1], S.A. Paranjpe[1] and A.P. Gore[1]
Marathwada Agricultural University, Parbhani

SUMMARY

Groundnut is an oilseed crop of prime importance in India. Rust inducing fungus *Puccinia arachidis* is responsible for loss of yield as high as 75% in Groundnut. A logistic growth model was fitted to each set of observations on growth of fungus. The two main parameters of the model namely exponential growth rate (r) and saturation level (k) were related to weather parameters. Temperature, humidity and rainfall during the first fortnight of the fungal attack were found to explain 80% variation in the values of the parameters. The paper concludes with suggestions arising out of the model towards better control of the rust disease.

Key words: Logistic growth model, Arcsine transformation, Weather parameters.

1. Introduction

Maharashtra State is one of the major producers of groundnut which is an oilseed crop of prime importance in India. Prior to seventies, Marathwada region within the State had extensive area under the crop, so that the Regional Oilseed Research Station of ICAR was located at Latur in Marathwada. Surprisingly, later the emphasis of work in this station had to be shifted to sunflower because of reduction in area under groundnut. The production of groundnut declined by 35% and area decreased by 25% during 1976-83. (Mayee [1]).

It is well known that rust epidemics coupled with other foliar and soil borne diseases prompted this decline.

Rust disease has limited the overall groundnut production in the State of Maharashtra by lowering yields of the rainy (*kharif*) season crop and by promoting the process of reduction of area under groundnut in this season. Interestingly, summer cultivation of groundnut gained, momentum after 1976. High yields of summer-season groundnut have, to some extent, compensated for the yield reduction in rainy season crop. However, the scope for further increase in production through expansion of area under summer cultivation is

1 Department of Statistics, University of Pune, Pune-411007

restricted due to limited irrigation. Hence it is time to concentrate on increasing and stabilizing production of rainy season crop. This makes search for appropriate disease management strategies imperative.

It is therefore of practical importance to study the growth pattern of the disease caused by *Puccinia arachidis.*

Section 2 describes the data used. A logistic growth model was fitted to these data. The results are given in Section 3. The logistic growth model has two parameters, the growth rate (r) and the saturation level (k). In Section 4 results are presented to relate these to weather parameters, such as temperature, humidity and rainfall in the initial phase of attack.

The last section suggests possible use of such modelling to control the fungus growth in a better way.

2. *Data*

The data used here are based on a monthly nursery experiment conducted at the Marathwada Agricultural University during 1978-83. In this experiment groundnut was sown on 5th day of every calendar month, rust inoculation was done on 30th day from sowing of the crop. Mayee *et al* [2] gives the details of experimental design. Groundnut was sown in each month for 5 successive years. (June 1978 to May 1983). Thus there were 60 replicates and for each replicate rust severity %, from 10th day of inoculation (40th day of plant age) to 90th day of inoculation (120th day of plant age) were recorded. The corresponding weather parameters namely rainfall, humidity (min, max), temperature (min, max) obtained from India Meteorological Department are used.

It was observed that growth of fungus varied considerably between replicates. Table 1 gives month wise maximum severity observed in each of 5 years.

It is noticed that rust grows to considerable extent on crops sown from April/May to November as against those sown in December to March. 1982-83 seems to be an exception in the sense that, in that year severity is low in almost every month as compared to other 4 years.

Same data are presented in Figure 1. This figure also shows the % rust severity on 10th day from inoculation. The severity is higher for sowing months April-November and lower for December-March. Again the year 1982-83 appears to be the odd one.

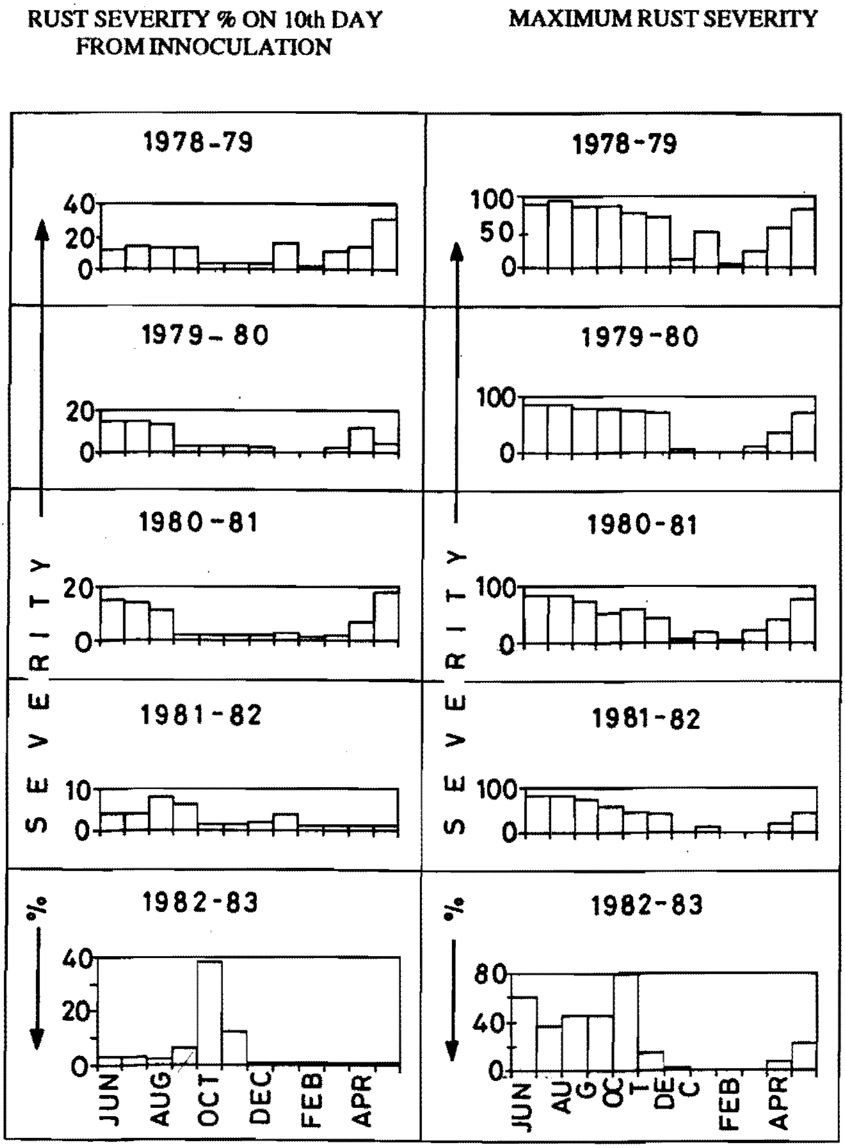
RUST SEVERITY % ON 10th DAY FROM INNOCULATION
MAXIMUM RUST SEVERITY
1978-79
1979-80
1980-81
1981-82
1982-83
SEVERITY %
JUN
AUG
OCT
DEC
FEB
APR

Fig. 1

For further analysis 21 sets of low severity (≤ 20%) (marked by * in Table 1) have been dropped.

For the remaining 39 sets the logistic growth model was fitted to summarize growth pattern.

Table 1 :Maximum severity (%) of Groundnut Rust *Puccinia arachidis* by year and month of sowing

Year / Month	1978-89	1979-80	1980-81	1981-82	1982-83
June	88	85	84	82	60
July	95	86	83	82	36
August	85	79	74	75	45
September	86	76	52	57	45
October	77	73	59	44	**78
November	72	70	44	42	*14
December	*10	*7	*6	*4.5	*2
January	49	*0	*20	*8	*1
February	*4	*0	*4	*2	*0.5
March	*23	*11	*21	*1	*1
April	58	36	43	*20	*7
May	**81	70	76	45	22

* low intensity, dropped from further analysis

** high, unusual initial severity (> 30%)

3. *Logistic Growth Model for Development of Groundnut Rust*

The population growth of a species can often be modelled well by Sigmoidal curves. Two commonly used models are (i) Logistic and (ii) Gompertz. Logistic model is fitted when a logit transformation makes the growth linear, while Gompertz model is suitable when double log transformation is needed to linearise the growth. Mayee *et al* [2] compared the two models. They found that for all practical purposes either model is as good as the other. We fit the following logistic model to 39 sets. Let p_t be the % of severity at time t. Then the logistic form for p_t is

$$p_t = \frac{P_{max}\, e^{Y_t}}{1 + e^{Y_t}}$$

Further $Y_t = \ln \frac{P_t/P_{max}}{1 - P_t/P_{max}}$ is the linearising transformation that gives

$$Y_t = \alpha + rt, \quad t = 1, \ldots, 9$$

Initially take observed maximum severity P_{max} (sometimes denoted by k) as given and estimate α and r by least squares. The final estimates are obtained by non-linear least squares by grid-search method. The grid was formed for P_{max} and r. Estimate of α follows directly when these two are known. Thus

$$S = \sum_{t=1}^{9} \left(p_t - \frac{P_{max} e^{\alpha + rt}}{1 + e^{\alpha + rt}} \right)^2$$

was minimized.

The results are given in Tables 2A, 2B and 2C.

The observed percentage of initial severity in Table 2A range between 1.5 and 15. There are a couple of outliers above 30%. The fitted logistic curves yield estimated values of the initial percentage which are fairly close.

Table 2A: Observed and estimated initial severity (percentage)

Year / Month	1978-79	1979-80	1980-81	1981-82	1982-83
June	10.0	15.0	15.0	4.0	3.0
	9.7	10.6	12.0	7.6	5.4
July	15.0	15.0	14.0	4.0	3.0
	12.2	11.1	11.2	7.2	4.7
August	12.0	13.0	11.0	8.0	2.0
	11.7	8.0	9.4	8.6	2.6
September	12.0	3.0	2.0	6.0	6.0
	11.9	5.5	3.6	7.8	4.9
October	3.0	3.0	2.0	1.5	38.0
	3.4	2.5	3.6	3.6	39.2
November	3.0	3.0	2.0	1.5	–
	4.4	7.9	0.3	0.5	–
January	17.0	–	–	–	–
	19.7	–	–	–	–
March	–	–	2.0	–	–
	–	–	0.9	–	–
April	15.0	12.0	7.0	–	–
	4.1	10.5	6.1	–	–
May	32.0	4.0	18.0	1.0	1.0
	33.7	3.5	20.1	2.4	0.6

Table 2B : Observed and estimated maximum severity (percentage)

Year / Month	1978-79	1979-80	1980-81	1981-82	1982-83
June	88.0	85.0	84.0	84.0	60.0
	92.3	90.2	89.5	93.2	72.7
July	95.0	86.0	83.0	82.0	36.0
	100.0	93.5	88.8	91.5	43.3
August	85.0	79.0	74.0	75.0	45.0
	88.8	82.0	77.5	78.4	73.0
September	86.0	76.0	52.0	57.0	45.0
	100.0	100.0	53.0	59.5	51.4
October	77.0	73.0	59.0	44.0	78.0
	91.2	89.6	100.0	45.0	83.2
November	72.0	70.0	44.0	42.0	–
	75.7	76.8	45.0	48.7	–
January	49.0	–	–	–	–
	50.0	–	–	–	–
March	–	–	21.0	–	–
	–	–	22.0	–	–
April	58.0	36.0	43.0	–	–
	100.0	43.3	44.0	–	–
May	81.0	70.0	76.0	45.0	22.0
	94.6	73.9	100.0	73.0	38.4

Table 2C : Estimated growth rate and residual sums of squares as % of total sums of squares.

Year / Month	1978-79	1979-80	1980-81	1981-82	1982-83
June	0.77	0.72	0.66	0.58	0.52
	98.0	97.4	98.3	95.7	94.8
July	0.68	0.67	0.67	0.60	0.45
	97.6	96.0	98.4	95.4	96.7
August	0.67	0.86	0.70	0.66	0.49
	99.5	97.8	98.0	99.5	96.8
September	0.38	0.45	0.76	0.62	0.63
	93.5	95.4	99.3	98.1	99.0
October	0.59	0.61	0.45	0.68	0.31
	99.6	98.8	96.7	97.3	98.8
November	0.69	0.42	1.23	0.92	–
	98.8	89.9	98.9	99.0	–
January	0.74	–	–	–	–
	96.2	–	–	–	–
March	–	–	0.95	–	–
	–	–	99.0	–	–
April	0.41	0.66	1.00	–	–
	98.6	96.4	97.9	–	–
May	0.51	0.76	0.40	0.49	0.58
	98.3	98.1	98.0	95.7	97.4

The estimates of maximum severity in Table 2B are also generally close to observed values. By the way this estimation is done, observed value is always below estimated value. Observed values range between 21% and 95%. Cases with values below 20% were ignored.

The estimates of exponential growth r in Table 2C range from 0.3 to 0.95. An exceptional case is 1.23. The proportion of variation in data explained by the logistic growth model is generally very high, in all cases above 89%. Thus the logistic models does a good job.

A question of interest is how far do the initial and maximum severities or growth rate vary over months and years.

The severity is recorded as %. Hence data were transformed using arcsine transformation and two way analysis of variance with months and years as factors was carried out. (Tables 3A, 3B, 3C).

Table 3A : Analysis of variance for severity on 10th day (arcsine transformed data)

Source	DF	Seq SS	Adj SS	Adj MS	f	P
Month	7	0.034455	0.038861	0.005552	3.61	0.099
Year	4	0.031029	0.031029	0.007757	5.04	0.005
Error	23	0.035370	0.035370	0.001538		
Total	34	0.100854	–	–	–	

Table 3B: Analysis of variance for maximum severity (arcsine transformed data)

Source	DF	Seq SS	Adj SS	Adj MS	f	P
Month	7	0.76885	1.09950	0.15707	13.69	0.000
Year	4	1.20650	1.20650	0.30163	26.29	0.000
Error	23	0.26383	0.26383	0.01147		
Total	34	2.23919	–	–	–	

Table 3C: Analysis of variance for growth rate r
(arcsine transformed data)

Source	DF	Seq SS $\times 10^{-6}$	Adj SS $\times 10^{-6}$	Adj MS $\times 10^{-6}$	f	P
Month	7	36.512	36.427	5.2039	1.49	0.220
Year	4	4.9344	4.9344	1.2336	0.35	0.839
Error	23	80.267	80.267	3.4899		
Total	34	121.7	–	–	–	

The results show that initial and maximum severities do change over months as well as over years. However, fluctuations in estimated growth rate do not show significant effect of month or year.

These tables show that the seasonal effects noticed in Figure 1 are statistically significant in case of initial severity on 10th day of inoculation and maximum severity but not in case of r.

4. *Relating Fungal Growth with Weather*

For the management purpose it will be useful to know the weather conditions that determine initial growth of fungus, the growth rate in exponential phase and maximum severity likely to occur.

Hence we attempted regressing

(i) 10th day severity

(ii) observed maximum severity and

(iii) growth rate on weather parameters

(A) Regression of 10th day severity on weather conditions during previous 10 days (from day of inoculation to 10th day).

Following strategy was adopted to explore the relation between weather and fungal growth. In stage 1, individual features of daily weather were taken one at a time from minimum temperature, maximum temperature, relative humidity 1 and 2, daily rainfall and sunshine hours. The values of that variable on several preceding days were treated as a group of regressors. Out of these a small subset was selected on the basis of significance of the associated coefficients. Such identified days for all parameters were considered together for regression in the second step. Variables were again screened to select the final model. The 'best' such regression for initial severity (transformed) is

$$y = -11.17 + 0.067 \text{ Min } T_3 + 0.141 \text{ RH2 (9th day)} - 0.054 \text{ Rainfall (6th day)}$$

Here R^2 was found to be 50%.

Clearly, weather parameters during preceding 10 days have only a limited impact on fungal severity (if low severity months are excluded).

(B) In case of growth rate and maximum severity the predictor variables were weather parameters and 10th day severity.

The 'best' regression equation for predicting growth rate is,

$$r = 0.336 - 0.004 \text{ (10th day severity)} + 0.034 \text{ (sunshine hours 15th day)} - 0.016 \text{ (sunshine hours 19th day)} - 0.007 \text{ (RH1 on 7th day)} + 0.009 \text{ (RH1 on 8th day)}$$

This gives R^2 of 66%. The earlier results of analysis of variance of growth rate suggest that month and year effects are insignificant. This means that on a broader scale, growth rate does not depend on season. However, the present regression analysis shows that, the relative humidity 3 days before the attack was noticed and sunshine hours in next 10 days may help in explaining fluctuations in growth rate to a moderate extent.

(C) The 'best' regression equation for maximum severity was

$$P_{max} = 112.75 + 0.52 \text{ (10th day severity)} - 3.48 \text{ (max T 10th day)}$$
$$+ 2.16 \text{ (min T 7th day)} + 2.49 \text{ (sunshine hours 8th day)}$$
$$- 1.30 \text{ (sunshine hours 9th day)} + 3.02 \text{ (sunshine hours 10th day)}$$
$$+ 2.00 \text{ (sunshine hours 11th day)} - 4.54 \text{ (sunshine hours 12th day)}$$

This gives $R^2 = 80\%$. Hence, once the attack is noticed, then temperature and sunshine hours 3 days before and 3 days after that day, predict the extent the disease is likely to intensify.

5. *Discussion*

It is clear that logistic growth model can adequately describe the development of fungus *Puccinia arachidis* on groundnut. Of the three parameters, the maximum severity level attained by the disease, is well estimated using weather information from about 35th day (from sowing) to about 50th day and initial level of severity. Thus the maximum severity can be anticipated about 50 days ahead of time.

This advance warning needs to be utilised in crop management. Two possibilities can be thought of. One is a prophylactic spray of fungicide and timely scheduling of spray. The other is a possible extra dose of macro or micronutrient. If a nutritional deficiency makes the crop more vulnerable to fungal attack, (Mayee [1]) remedial measure can be undertaken. If the crop is sown in December-March one can expect no serious problem with *Puccinia arachidis*.

The present analysis therefore suggests that weather information can be put to use in improving crop management of groundnut.

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