International Journal of Current Science Research
www.drbgrpublications.in

Volume: 6; Issue: 4; April-2020; pp 1950-1963. ISSN: 2454-5422

Assessment of Progression of Field Bean Anthracnose by Using Mathematical Tools and Growth Models

S. Narasimha Rao[1*], SL. Bhattiprolu[2] and V. Sekhar[3]

[1]Department of Plant Pathology, College of Horticulture, Dr. YSRHU, VR Gudem, India
[2]Regional Agricultural Research Station, ANGRAU, Lam, Guntur, India
[3]Department of Statistics, College of Horticulture, Dr. YSRHU, VR Gudem, India
[*]Corresponding author email id: varsha.snrao@gmail.com

Abstract

Mathematical tools and growth models show the dynamics of disease development over time and information obtained can be used to implement the effective cultural and control measures. In the present study lowest progress of per cent disease index (30.46%), area under disease progress curve (1269.50) and rate of infection for logit and gompit (0.47 and 0.18) were recorded in three sprayings of thiophanate methyl. Anthracnose was progressed from 45 to 108 DAS and thereafter declined in fungicidal spray plots. Gompertz model was observed to be the best fitted in assessment of field bean anthracnose severity in comparison to the Logistic model.

Keywords: Anthracnose, AUDPC, disease models, progress curves, rate of infection

Introduction

Nowadays plant diseases reduce the yield both qualitatively and quantitatively, In case of field bean, anthracnose pathogen infects the various plant parts. Mathematical tools have been employed to know the appearance of disease, amount of inoculum, progress of disease development and changes in host susceptibility during growing crop period. Growth models provide a range of curves that are often similar to disease progress curves (Van Maanen and Xu, 2003) and represent one of the most common mathematical tools to describe temporal disease development (Xu, 2006). Field bean (*Dolichos lablab* var *lignosus* L.) anthracnose caused by *Colletotrichum lindemuthianum* is an important polycyclic foliar fungal disease that occurs throughout the world and infects all above ground plant parts including pods and seeds thereby adversely affecting the yield (Melotto and Kelly, 2000). The pathogen overwinters or over summer inside the seed and infected plant residues of about 2 years (primary source of infection) (Tochinai and Sawada 1952). The secondary spread achieved by conidia produced from the infected plant parts and are disseminated by wind for 3-5 meters (Nyvall, 1989). Hence, knowledge on disease initiation and progressive of disease development is at most necessary. Such information helps to know the congenial periods for disease development and make the need based implementation of various management strategies that will curb the anthracnose of field bean incidence and also curtail cost of plant protection. Keeping in view, mathematical tools like per cent disease index, area under disease progress curve (AUDPC) and apparent rate of infection similarly growth models like logistic and gompertz models were used to obtain information about the appearance and amount of inoculum by employing the different spraying schedules with thiophanate methyl (0.1%) as foliar application against the field bean anthracnose.

Materials and Methods

The field experiments were conducted in two consecutive seasons at instructional farm, College of Horticulture, V.R. Gudem during 2016-17 and 2017-18 using field bean variety Arka Amogh sown at spacing of 60 x 30 cm. The experimental crop was raised as per the package of practices of Dr. YSR Horticultural University, Andhra Pradesh. The field experiment was laid out in randomized block design with six replications and four treatments *viz.*,

T_1- One spray at the onset of disease (45 days after sowing (DAS)

T_2- Two sprays, at T_1 + 10 days after T_1 (Two sprays at 45 and 55 DAS)

T_3- Three sprays, at T_1+ T_2+10 days after T_2 (Three sprays at 45, 55 and 65 DAS)

T_4- No sprays (without fungicide application).

The sprays under T_1, T_2 and T_3 were initiated from 45 days after sowing irrespective of disease appearance due to the assumed incidence of the disease every year and subsequent applications at an interval of 10 days. Observations on disease severity were recorded on five point scale as given by Mayee and Datar (1986). Fifteen plants from each plot were selected and labeled randomly for scoring the progress of disease. Disease severity was recorded by observing three trifoliate leaves, one each from base, middle and upper portion of the selected plants from 45 DAS to 129 DAS and per cent disease index (PDI) was calculated by formula suggested by Wheeler (1969). Further disease progress was assessed by disease progress curves like area under disease progress curve and apparent rate of infection and growth models like Logistic and Gompertz.

Area under disease progress curve (AUDPC) - AUDPC was computed from the per cent of disease index (PDI) data recorded at each date of assessment as described by Wilcoxson *et al.* (1975). AUDPC was expressed in per cent days because the severity (x) was expressed in per cent and time (t) in days and was calculated by using the formula.

$$AUDPC = \sum_{i=1}^{k} \frac{1}{2} (S_i + S_{i-1})(T_{i-1} - T_i)$$

Where,

S_i = Severity of anthracnose at the end of time i

k = Number of successive evaluation of anthracnose

T_{i-1}-T_i = Time interval between two evaluations i-1 and i of the disease

Apparent infection rate (r=unit/day) - Disease progress in time was studied by recording the severity of disease at seven days interval right from appearance of first disease symptoms till the final harvest of the crop in different treatments. Disease severity values were transformed into logit and gampit as per the description of Van der Plank (1963) and Berger (1981), respectively, following equations.

Logistic : Logit (X) = In (X /(1- X))

Gompertz : Gompit (X) = -In (-In(X))

Where,

X = proportion of diseased tissue,

(1-X) = the proportion of tissue available for infection.

The rates of disease progress were obtained from the regression of the PDI data fit to Logistic and Gompertz model with dates of assessments. Apparent infection rate was calculated either as logistic infection rate (r) or Gompertz infection rate (k), for each increment of time determined using the respective formulae of Van der Plank (1963) and Berger (1981).

Logistic model

$$r = \text{logit}(X_2) - \text{logit}(X1)/(t_2 - t_1)$$

Where,

r = rate of disease increase per week for logit

X_1 = Disease severity at time t_1

X_2 = Disease severity at time t_2

Gompertz model

$$k = - \text{In}\ (- \text{In}\ X_2) - \text{In}\ (-\text{In}\ X_1)/\ (t_2-t_1)$$

Where,

k = rate of disease increase per week for gompit

X_1 = Disease severity at time t_1

X_2 = Disease severity at time t_2

The goodness of fit to the model was evaluated by co-efficient determination (R^2), adjusted determination of co-efficient (adj. R^2) and standard error of estimation (SEE). So, a final evaluation of the model was determined based on the above three criteria (Berenson *et al.*, 1983).

Results and Discussion

Establishing the relationship between disease severity at different stages of crop development and subsequent progress of disease is needed for decision making an alternative disease management strategy. Experiments on the progress of field bean anthracnose were conducted during *Rabi* 2016-17 and 2017-18 using three spray schedules of thiophanate methyl at different intervals and results obtained were presented here under.

Per cent disease index (PDI)

Disease severity values were higher on control plots throughout the assessment periods than the plots that received the thiophanate methyl spray till 129 DAS. Fungicide sprays were at par up to 73 DAS; thereafter significant difference was noticed in fungicide treatments. At 80 DAS, plots received two and three sprays were at par and significantly superior over the single sprayed plots. Significant difference among the fungicide application was observed from 87 DAS to 129 DAS. At 87 DAS lowest PDI (14.08) was recorded plots received the three rounds of spraying and highest was noticed with the control (25.80%).The lowest terminal PDI (29.58) was observed in plots sprayed with three times of thiophanate methyl and was significantly superior over the other treatments, while highest PDI was recorded in control (54.60) during 2016-17 (Table 1).

The disease severity of anthracnose for year 2017-18 revealed that non significant differences were noticed between the treatments at 45 DAS and fungicide sprays were non significant up to 66 DAS, thereafter significant difference was noticed in fungicide treatments. Up to 94 DAS, plots received the two and three sprays were at par and significantly superior to the single sprayed plots. Significant difference among the fungicide application was observed from 101 DAS to 129 DAS. At 101 DAS lowest PDI (21.00) was recorded in plots received the three rounds of spraying and highest was noticed with the control (36.17). The lowest terminal PDI (31.33) was observed in plots sprayed three times of thiophanate methyl and was significantly superior to the other treatments and highest PDI was recorded in control (55.77) (Table 1).

Pooled data of two years indicated that, all the treatments were significantly differed from each other from 45 DAS to 129 DAS. All the fungicide treatments were non significant up to 66 DAS and plots sprayed with twice and thrice were at par with each other up to 87 DAS and thereafter all the fungicide sprays were significantly differed from each other in controlling field bean anthracnose. The lowest terminal PDI in plots sprayed with three rounds (30.46) of thiophanate methyl was significantly superior to the other treatments and highest was recorded in control (55.18) (Table 2).

Progress of per cent disease index

The progress of disease index was worked out in all the treatments, per cent disease index increased from 45 DAS to 94 DAS with 1.17 to 5.42 and 2.00 to 4.55 in plots received the one, and two sprays, respectively, thereafter declined gradually. In case of plots received three sprays increased disease index up to 108 DAS with 1.43 to 3.25 and thereafter declined gradually during 2016-17 (Fig. 1).

Similarly during 2017-18 the disease progress was observed in all the treatments from 45 DAS to 101 DAS with 1.58 to 5.80 and 2.08 to 4.75 plots received the one and two sprays, respectively, thereafter declined gradually. In case of plots received the three sprays disease was progressed up to 108 DAS and thereafter declined gradually (Fig 1).

The pooled data on progress of disease revealed that, disease increased from 45 DAS to 101 DAS with 1.38 to 5.11 and 2.04 to 4.22 plots received one and two sprays, respectively, thereafter declined gradually. In case of plots received the three sprays increased disease index up to 108 DAS and thereafter declined gradually. The disease progress was very fast in control compared fungicide sprayed plots (Table 3).

Disease was progressed at linear rate in control plots throughout assessment period in both the years. This could be due to the accumulation of secondary inoculum, susceptibility of the crop's stage and or the occurrence of favorable environmental conditions. While in case of fungicidal spray plots disease progressed comparatively slow rates than control. These results are supported by the findings of Tesfaye (1997) where a mean severity of 59.30 at the podding stage of haricot bean.

Area under diseases progress curve (AUDPC)

The AUDPC analysis showed the overall disease development was significantly affected by the number of spraying schedules imposed. The increase in disease throughout the assessment period indicated the spread of the disease in space. The data showed highly significant differences among treatments. The results in Table 4 revealed that AUDPC was higher in control plots (unsprayed) as compared with fungicide sprayed plots in both the years.

The difference in AUDPC with number of fungicide application was statistically significant. Highest AUDPC value was obtained in control plots with 2224.72 and 2315.72 during 2016-17 and 2017-18, respectively (Table 4). The lowest AUDPC was obtained in plots with three rounds of fungicide application during 2016-17 and 2017-18. The study showed that the pathogen *C. lindemuthianum* grew faster in unsprayed plots than the protected plots. The results of the experiment clearly indicate that three times applications of fungicide is sufficient to reduce the disease levels.

Significantly different AUDPC results were obtained, indicating that anthracnose progressed differently among spray schedules. These findings are in accordance with result of Patil (1997) and found that reduction in AUDPC values of sunflower rust with increase in number of mancozeb sprays and also by Amaresh and Nargund (2004) that AUDPC values of *Alternaria* leaf blight (ALB) and rust of sunflower were low in higher number of sprays of chlorothalonil, but low for ALB by iprodion treatment.

The above study indicated that, anthracnose progressed significantly in all the spraying schedule except 45 DAS and further thiophanate methyl effectively control the anthracnose in plots received the three rounds of spraying. Spray schedules/intervals showed the period of effectiveness of thiophanate methyl. Based on above data, effective period thiophanate methyl in controlling the anthracnose was varied from 10-15 days after spraying. During the 2016-17, plots with single spray recorded the PDI of 5.00 were at par with twice (4.83) and thrice (4.25) up to 59 DAS and similarly plots sprayed twice (11.67) were at par with thrice (11.25) up to 80 DAS.

During 2017-18, plots with single spray noticed the PDI of 7.88 were at par with twice (7.67) and thrice (6.92) up to 66 DAS and similarly plots sprayed twice (20.75) were at par with thrice (17.92) up to 94 DAS. Pooled data of two years also indicated that, spraying with once (7.48) were at par with twice (7.21) and thrice (6.50) up to 66 DAS and similarly spraying with twice (16.35) were at par with thrice (14.54) up to 87 DAS. The progress of disease decreased after 110 DAS may be due to saturation of the pathogen in the host population, decline of proneness of the host and non availability of new tissue to the pathogen.

Apparent rate of infection (r or k)

Disease progress rates were calculated from disease severity data collected thirteen times after the symptom appearance and progression rates were compared between the different spraying intervals during crop growth. The PDI values were converted into logit and gompertz transformation and results showed the significant difference between the logit ‘r’ and gompit ‘k’ in both the years. Logit ‘r’ increased at an apparent rate *i.e* logit ‘r’ of 0.46 logit/day to 0.62 logit/day and 0.47 logit/ day to 0.57 logit/day, respectively, during 2016-17 and 2017-18. Plots received two times applications of fungicide had the lowest logit ‘r’ (0.46 and 0.47) during 2016-17 and 2017-18, respectively (Table 4).

Similarly for Gompit ‘k’ increased at an apparent rate *i.e.*, gompit ‘r’ from 0.18 gompit/day to 0.27 gompit/day in both the years. The highest gompit ‘k’ (0.27 and 0.26) and lowest gompit ‘k’ (0.18 and 0.18) was noticed in plots received three times applications of fungicide during 2016-17 and 2017-18, respectively (Table 4). These results are in accordance with Amin and Ullase (1981) and reported apparent infection rates were higher on unsprayed plots than on sprayed ones.

Non-linear regression of disease severity

Comparisons of the rates of disease development among the spraying schedules were subsequently made based on the Logistic and Gompertz model by fitting the PDI data with dates of assessment. Logistic equation (Y=a/(1+Exp(-b(x-c))) and Gompertz equation (Y= a*Exp(-Exp(b-cx))) models and the results of the model concluded that both the models can be equally fit to depict the disease progression over time because of R^2 values and correlation co-efficient were more than 99.0 per cent but lower standard error of estimation in Gompertz model suggested that Gompertz fit better than Logistic in case of anthracnose of field bean. Logit model, it was best fit in three times applied plots with (r=0.344 and

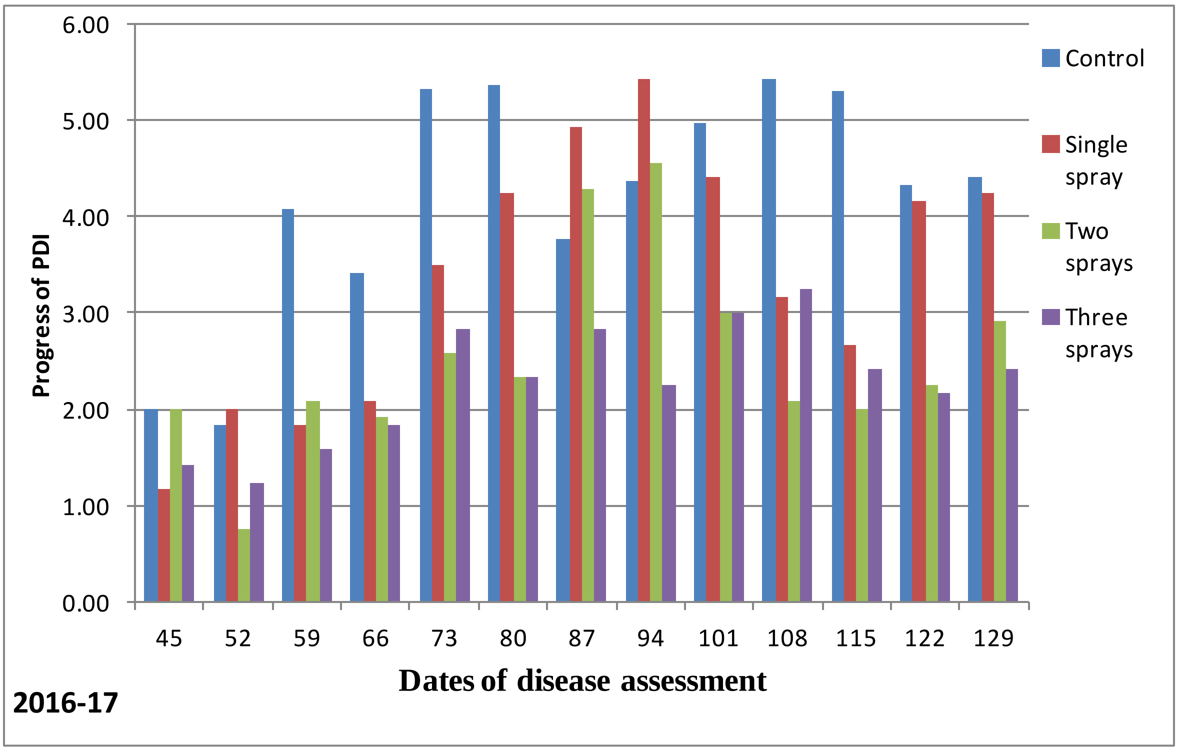
0.362; b=0.367 and 0.377, c= 8.223 and 7.96 with SEE value=0.00696 and 0.00472) in the year 2016-17 and 2017-18, respectively. In case of Gompertz transformation the apparent infection rate (a), rate of change in apparent infection with time (b) and maximum carrying capacity of disease (c) were 0.424 and 0.471, 0.216 and 0.179,1.456 and 1.377, respectively, during 2016-17 and 2017-18, where the plots received the two and three applications of fungicide (Tables 5 and 6).

The results of two years data (pooled data) indicated that, apparent infection rate (a), rate of change in apparent infection with time (b) and maximum carrying capacity of disease (c) were 0.351 and 0.457, 0.373 and 0.177, 8.025 and 1.377, respectively, for logistic and Gompertz regressions for the plots received the three sprays of fungicide and had highest R^2 of 0.998 for both the models (Tables 5 and 6). Experimental data showed that the rates of disease increase were considerably influenced by the number of initial disease foci. In an experiment with Southern blight of processing carrot, the rate of disease increase generally increased as the number of initial foci increased (Smith *et al.*, 1988 and Xu and Ridout, 1998). At the end of the field bean cycle, there was a reduction in the amount of disease estimated, which could be due to the reduction in the availability of healthy tissue for new infections.

Conclusion

The progress of disease was higher side from 45 DAS onwards in unsprayed plots and plots received single spray was at par with two sprays and three sprays up to 66 DAS. Similarly plots received two sprays were at par with three sprays up to 87 DAS. This present study fungicide sprayings control the disease up to 87 DAS and then disease progressed continuously after 94 DAS till the final harvest. The study indicated once spraying schedule was stopped the disease was increased due to the pathogen developed secondary inocula and severely affected the crop. Hence three sprayings of thiophanate methyl was essential to get the disease free pods and get higher yields.

Volume: 6; Issue: 4; April-2020; ISSN: 2454-5422



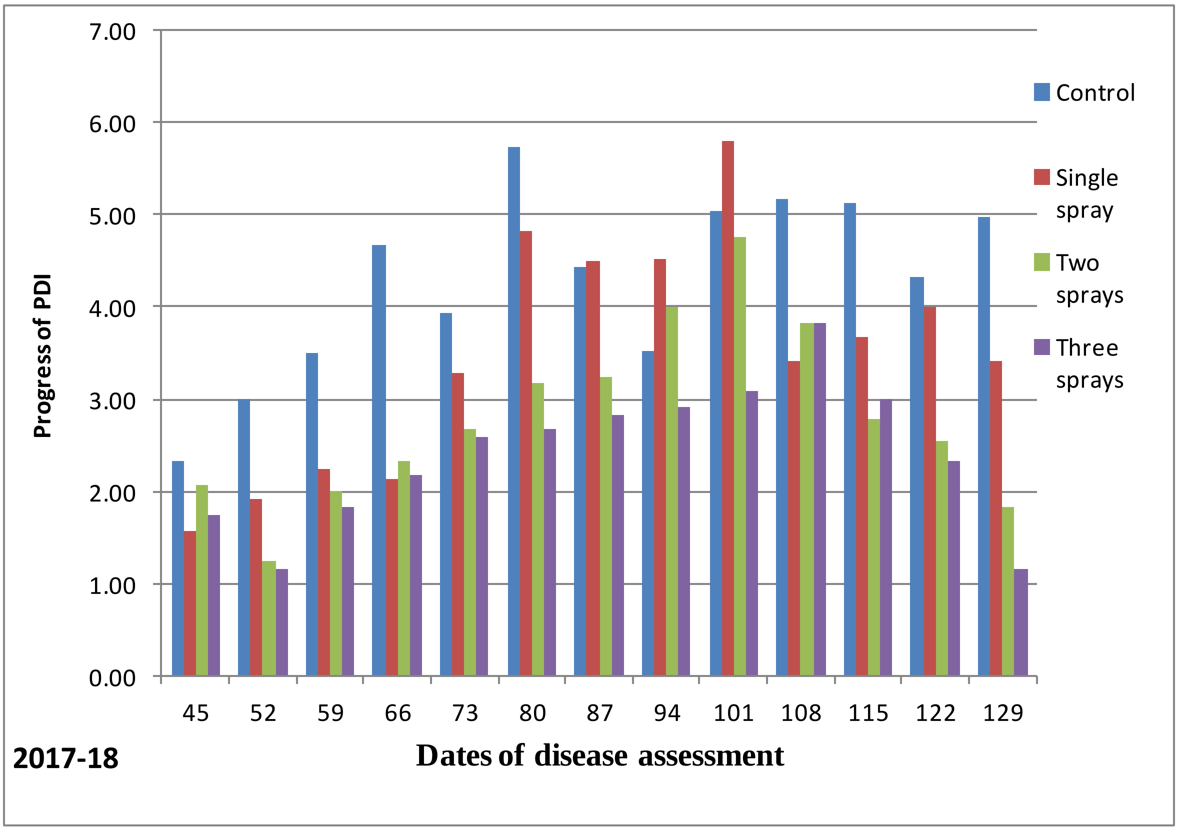


Fig 1: Effect of spraying schedules of thiophanate methyl on progress of per cent disease index of field bean anthracnose

Table 1: Effect of thiophanate methyl spraying schedule on per cent disease index of field bean anthracnose during 2016-17 and 2017-18

2016-17									
Treats.	**45 DAS**	**52 DAS**	**66 DAS**	**73 DAS**	**80 DAS**	**87 DAS**	**94 DAS**	**101 DAS**	**129 DAS**
Control	2.00* (8.04)**	3.83* (11.24)	11.33* (19.66)**	16.67* (24.08)**	22.03* (27.98)**	25.80* (30.51)**	30.17* (33.29)**	35.13* (36.33)**	54.60* (47.62)**
One spray	1.17 (6.04)	3.17 (10.22)	7.08 (15.32)	10.58 (18.95)	14.83 (22.63)	19.75 (26.37)	25.17 (30.09)	29.58 (32.93)	43.83 (41.44)
Two sprays	2.00 (8.05)	2.75 (9.49)	6.75 (15.04)	9.33 (17.74)	11.67 (19.94)	15.95 (23.24)	20.50 (26.90)	23.50 (28.98)	32.75 (34.89)
Three sprays	1.43 (6.84)	2.67 (9.38)	6.08 (14.22)	8.92 (17.30)	11.25 (19.55)	14.08 (22.02)	16.33 (23.82)	19.33 (26.06)	29.58 (32.93)
C.D (5%)	NS	1.18	1.11	1.82	1.46	1.22	1.36	1.38	1.08
SE(m)±	0.56	0.39	0.36	0.62	0.48	0.40	0.45	0.45	0.36
C.V (%)	18.97	9.40	5.53	7.49	5.21	3.85	3.83	3.57	2.22
2017-2018									
Treats.	**45 DAS**	**52 DAS**	**66 DAS**	**73 DAS**	**80 DAS**	**87 DAS**	**94 DAS**	**101 DAS**	**129 DAS**
Control	2.33* (8.74)**	5.33* (13.34)**	13.50* (21.52)**	17.43* (24.66)**	23.17* (28.75)**	27.60* (31.661)**	31.13* (33.88)**	36.17* (36.94)**	55.77* (48.30)**
One spray	1.58 (7.09)	3.50 (10.68)	7.88 (16.23)	11.17 (19.40)	16.00 (23.56)	20.50 (26.90)	25.03 (30.00)	30.83 (33.71)	45.33 (42.31)
Two sprays	2.08 (8.27)	3.33 (10.49)	7.67 (16.06)	10.33 (18.72)	13.50 (21.53)	16.75 (24.14)	20.75 (27.04)	25.50 (30.29)	36.50 (37.15)
Three sprays	1.75 (7.49)	2.92 (9.79)	6.92 (15.23)	9.50 (17.93)	12.17 (20.39)	15.00 (22.75)	17.92 (25.02)	21.00 (27.24)	31.33 (34.02)
C.D (5%)	NS	1.33	1.56	1.21	1.41	1.66	2.18	2.13	1.04
SE(m)±	0.45	0.44	0.51	0.40	0.46	0.55	0.72	0.70	0.33
C.V (%)	14.00	9.67	7.28	4.81	4.82	5.08	6.05	5.36	2.01

DAS = Days After Sowing
* Mean of six replications
** Figures in parentheses are arc sine transformed values

Table 2: Effect of thiophanate methyl spraying schedule on per cent disease index (Pooled data 2016-2018)

Treatments	45 DAS	52 DAS	66 DAS	73 DAS	80 DAS	87 DAS	94 DAS	101 DAS	129 DAS
Control	2.17* (8.41)**	4.58* (12.30)**	12.42* (20.61)**	17.05* (24.38)**	22.60* (28.37)**	26.70* (31.09)**	30.65* (33.59)**	35.65* (36.64)**	55.18* (47.96)**
One spray	1.38 (6.61)	3.33 (10.40)	7.48 (15.77)	10.88 (19.17)	15.42 (23.10)	20.13 (26.64)	25.10 (30.05)	30.21 (33.32)	44.58 (41.87)
Two sprays	2.04 (8.18)	3.04 (10.03)	7.21 (15.56)	9.83 (18.24)	12.58 (20.75)	16.35 (23.83)	20.63 (26.97)	24.50 (29.64)	34.63 (36.03)
Three sprays	1.59 (7.22)	2.79 (9.60)	6.50 (14.75)	9.21 (17.63)	11.71 (19.98)	14.54 (22.69)	17.13 (24.43)	20.17 (26.66)	30.46 (33.48)
C.D (5%)	1.24	0.81	1.04	1.33	1.26	1.36	1.68	1.67	0.71
SE(m)±	0.41	0.27	0.34	0.44	0.41	0.45	0.55	0.55	0.23
C.V (%)	13.13	6.12	5.01	5.41	4.40	4.22	4.69	4.26	1.43

DAS = Days After Sowing
* Mean of six replications
** Figures in parentheses are arc sine transformed values

Table 3: Effect of thiophanate methyl spraying schedule on progress per cent disease index of field bean anthracnose (Pooled data)

DAS	Control	Single spray	Two sprays	Three sprays
45	2.17*	1.38*	2.04*	1.59*
52	2.42	1.96	1.00	1.20
59	3.79	2.04	2.04	1.71
66	4.05	2.11	2.13	2.00
73	4.63	3.39	2.63	2.71
80	5.55	4.54	2.75	2.50
87	4.10	4.71	3.77	2.83
94	3.95	4.98	3.88	2.59
101	5.00	5.11	4.22	3.04
108	5.30	3.30	2.96	3.54
115	5.22	3.17	2.39	2.71
122	4.33	4.09	2.40	2.25
129	4.69	3.84	2.38	1.80

DAS = Days After Sowing
* Mean of six replications

Table 4: Effect of spraying schedules of thiophanate methyl on AUDPC, logit and gompit rate of infection in field bean anthracnose

Treatments.	2016-17			2017-18			Mean		
	AUDPC	logit 'r'	Gompit 'k'	AUDPC	logit 'r'	Gompit 'k'	AUDPC	logit 'r'	Gompit 'k'
Control	2224.72	0.59*	0.27*	2315.72	0.57*	0.27*	2270.22	0.58	0.27
One spray	1702.18	0.62	0.24	1807.46	0.57	0.24	1762.69	0.59	0.24
Two sprays	1375.80	0.46	0.18	1530.38	0.47	0.19	1449.82	0.49	0.19
Three sprays	1212.27	0.48	0.18	1326.79	0.47	0.18	1269.5	0.47	0.18
C.D (5%)	75.35	0.07	0.02	97.54	0.05	0.01	78.92	0.06	0.01
SE(m)±	24.77	0.02	0.01	32.06	0.02	0.01	25.95	0.01	0.01
C.V (%)	3.72	10.53	5.84	4.50	8.09	5.18	3.77	7.54	6.34

Table 5: Non linear regression of Logistic model for rate of infection of anthracnose in field bean

Treatments	**2016-2017**					
	Parameters			**Statistics**		
	a	**b**	**c**	**R**	**R^2**	**SEE**
Control	0.626	0.366	8.109	0.997	0.994	0.0155
One spray	0.471	0.435	7.780	0.998	0.995	0.0114
Two sprays	0.347	0.433	7.300	0.998	0.997	0.00681
Three sprays	0.344	0.367	8.223	0.998	0.996	0.00696
	2017-2018					
Control	0.638	0.348	8.028	0.996	0.993	0.0157
One spray	0.499	0.413	7.967	0.999	0.998	0.0065
Two sprays	0.412	0.400	7.842	0.998	0.997	0.00329
Three sprays	0.362	0.377	7.960	0.997	0.998	0.00472
Pooled data						
Control	0.629	0.358	8.043	0.997	0.994	0.00149
One spray	0.483	0.423	7.899	0.998	0.997	0.00801
Two sprays	0.378	0.412	7.625	0.999	0.998	0.00325
Three sprays	0.351	0.373	8.025	0.999	0.998	0.00454

a=apparent infection rate

b= rate of change in apparent infection with time

c= Maximum carrying capacity of disease

R^2 = Regression

r= Correlation co-efficient

SEE = standard error of estimation

Table 6: Non linear regression of Gompertz model for rate of infection of anthracnose in field bean

Treatments	2016-2017					
	Parameters			Statistics		
	a	b	c	R	R^2	SEE
Control	0.805	0.177	1.377	0.999	0.998	0.00924
One spray	0.579	0.214	1.568	0.999	0.998	0.0081
Two sprays	0.424	0.216	1.456	0.997	0.995	0.00807
Three sprays	0.457	0.171	1.385	0.999	0.998	0.00479
	2017-2018					
Control	0.822	0.170	1.303	0.998	0.996	0.00919
One spray	0.641	0.197	1.510	0.999	0.998	0.00475
Two sprays	0.531	0.190	1.431	0.998	0.997	0.00582
Three sprays	0.471	0.179	1.377	0.997	0.994	0.00433
Pooled data						
Control	0.808	0.175	1.354	0.999	0.998	0.00823
One spray	0.613	0.204	1.545	0.999	0.999	0.00537
Two sprays	0.475	0.201	1.442	0.999	0.998	0.00489
Three sprays	0.457	0.177	1.377	0.999	0.998	0.0027

a=apparent infection rate

b= rate of change in apparent infection with time

c= Maximum carrying capacity of disease

R^2 = Regression

r= Correlation co-efficient

SEE = standard error of estimation

References

Amaresh, Y.S. and Nargund, V.B. Assessment of yield losses due angular leaf blight and rust of sunflower. *J. of Myco. and Pl. Pathol.*. (2004) 34: 75-79.

Amin, K.S. and Ullase, B.A. Effect of thiophanate on epidemic development of anthracnose and yield of watermelon. *Phytopatho*. (1981) 71: 20-22.

Bassanezi, R.B., Amorin, L., Bergamin Filho, A., Hau, B. and Berger, R.D. Accounting for photosynthetic efficiency of bean leaves with rust, angular leaf spot and anthracnose to assess crop damage. *Pl Pathol.* (2001) 50: 443-452.

Berenson, M., Sevine, D. and Goldstein, M. Intermediate Statistical Methods and application. Prentice Hall. (1983) XVII 579.

Berger, R.D. Comparison of the gompertz and logistic equations to describe disease progress. *Phytopathol.* (1981) 71: 718-719.

Mayee, C. D. and Datar, V.V. *Phytopathometry*. Technical bulletin-I. Marathwada Agricultural University, Parbani. (1986) 85.

Melotto, M. and Kelly, J.D. An allelic series at the Co-1 locus conditioning resistance to anthracnose in common bean of Andean origin. *Euphytica*. (2000) 116: 143-149.

Nyvall, R.F. Diseases of common bean (*Phaseolus vulgaris* L.). Field crop diseases Handbook (2nd edition). Van Nostrand Reinhold, New York. (1989) pp 222-223.

Patil, P.V. Studies on sunflower rust caused by *Puccinia helianthi* Schw. *Ph.D. Thesis*, University of Agricultural Sciences, Dharwad. (1997) pp. 238.

Smith, V.L., Campbell, C.L., Jenkins, S.F. and Benson, D.M. Effects of host density and number of disease foci on epidemics of Southern blight of processing carrot. *Phytopathol*. (1988) 78: 595-600.

Tesfaye, B. 1997. Loss assessment study on haricot bean due to anthracnose. *Pest Mana. J. of Ethiopia*. (1997) 1 & 2: 69-72.

Tochinai,Y. and Sawada, K. Observations on the over wintering of the bean anthracnose fungus, *Colletotrichum lindemuthianum* Briosi and Cavara. Hokkaido Univ Fac. Agric. Mem. (1952) 1: 102-112.

Van der Plank, J.R. *Plant Diseases: Epidemics and Control*. Academic Press, London. (1963) 249.

Van Maanen, A. and Xu, X.M. Modelling plant disease epidemics. *European J. Pl. Pathol*. (2003) 109: 669-682.

Wheeler, B.E.J. *An Introduction to Plant Disease*. John Wiley, London. (1969) 347.

Wilcoxson, R.D., Skovamand, B. and Atif, A.H. Evaluation of wheat cultivars for ability to retard development of stem rust. *Annals of Appl. Biol*. (1975) 80: 275-281.

Xu, X. Modelling and interpreting disease progress in time. In: The epidemiology of plant disease. Cooke B. M, Gareth Jones D and Kaye B (eds) Springer, Dordrecht, The Netherlands, pp. (2006) 215-238.

Xu, X.M. and Ridout, M.S. Effects of initial epidemic conditions, sporulation rate and spore dispersal gradient on the spatio-temporal dynamics of plant disease epidemics. *Phytopathol*. (1998) 88: 1000-1012.