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Effect of Weather Variables on the Development of Field Bean Anthracnose at Different Dates of Sowing

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ABSTRACT: Weather variables has served a descriptive and predictive role by identifying and quantifying factors that lead to disease outbreak or cause spatial or temporal increase or decrease in disease severity. Accordingly studies on role of weather factors on the development of field bean anthracnose were conducted and results indicated that disease severity was significantly influenced by weather factors at different dates of sowing. Early infection, of about 5-7 days, occurred during 2017-18 irrespective of same dates of sowings as compared to during 2016-17. Progress of disease increased slightly from first week of November to last week of January or first week of February in both years and reached peak at 6th SWM, thereafter declined gradually due to raise in the temperature. During the major progress, mean maximum and minimum temperature were around 29.49ºC and 20.13ºC, respectively, whereas morning relative humidity was 86.05% with moderate rainfall. Correlation analysis showed positive significant correlation of per cent disease index with maximum temperature and sunshine hours; non significant correlation with minimum temperature and evaporation; significant negative correlation with evening relative humidity and rainfall. Multiple correlation co-efficient indicated strong relationship between disease severity and weather variables, thereby, contributed more than 95.10% variation during 2016-17 and 93.90% variation during 2017-18. Correlation and regression analysis of the disease with weather factors further confirmed their role in the disease development. The prediction equations developed in the present study helps in planning and execution of forecasting models.

Keywords*:* anthracnose, correlation, disease severity, field bean, regression, weather factors.

INTRODUCTION

Field bean (*Dolichos lablab* var. *lignosus* L.) is affected by a number of diseases limiting productivity of the crop. Among them, anthracnose (*Colletotrichum lindemuthianum*) is most important soil borne as well as seed borne pathogen causing yield losses nearly 80 to 100% under cool and humid environmental conditions (Sharma *et al*., 2007). The most important environmental factors that affect the development of plant disease are moisture, temperature and the activities of humans in terms of cultural practices (planting dates and irrigation systems) and control measures. And also edaphic factors such as soil temperature, soil moisture, soil pH and soil type. Meenu Gupta and Bhardwaj (2009) reported the high soil moisture (>75%), low temperature (15 ºC) and soils with slightly acidic pH (5.5) with sandy loam texture were found highly conducive for the development and spread of red stele disease of caused by *Phytophthora fragariae*. Heavy and frequent rains with moderate temperatures (19-25ºC) and high relative humidity (>70%) favoured the progress of anthracnose of kidney bean in terms of vertical and horizontal spread (Kumar *et al*., 1999). Though this disease can be managed up to some extent by the use of fungicides but environmental imbalance is the major problem to manage the disease, as disease is interaction between pathogen and host, which is influenced by environmental factors. Sowing date plays an important role in plant growth during the season and the final yield. Different dates of sowings were taken up to select the best sowing date for growing good crop under very low disease pressure. Hence, the present study aims at understanding the effect of sowing dates and weather factors on the severity of the field bean anthracnose and also to know the time or stage of initiation, progress and window period of the disease.

MATERIAL AND METHODS

Field experiments were conducted for two consecutive seasons at instructional farm, College of Horticulture, Dr. YSR Horticultural University V.R. Gudem during 2016-17 and 2017-18 using field bean variety, Arka Amogh with six different dates sowing starting from 4th week of September at an interval of seven days in a randomised block design with four replications. Uniform plant population with spacing of 60 × 30 cm was maintained. The experimental crop was raised as per the package of practices of Dr. YSR Horticultural

University, Andhra Pradesh. The meteorological data *viz.*, temperature (maximum and minimum), relative humidity at 08.00 h (RH_1) and at 14.00 h (RH_2), total rainfall, sunshine hours, evaporation and wind velocity was obtained from the Meteorological observatory at College of Horticulture, V.R. Gudem during the period of experimentation for two years. Weekly averages of weather parameters were calculated, except rainfall for which weekly total was used for correlation and regression studies.

Disease severity was assessed at weekly intervals starting from the appearance of 1^{st} disease symptom to till final harvest of first sown crop (26^{th} September in both years) on fifteen randomly selected plants on five point scale as given by Mayee and Datar (1986). Disease was scored by observing three trifoliate leaves, one each from base, middle and upper portion of the selected plants and per cent disease index (PDI) was calculated by formula of Wheeler (1969). For the purpose of correlation, environmental factors for a period of seven days prior to the date of recording disease severity were considered as first time data. Per cent disease index was subjected to correlation and multiple regression analyses with weather factors to determine the relationship between weather factors and disease development.

A. Correlation between disease and weather variables

The relationship between disease and various weather variables during the course of disease development was analyzed by calculating the simple and multiple correlation and regression co-efficient performed as per the method described by Gomez and Gomez (1984).

B. Regression co-efficient

The effect of various environmental factors on disease progress was estimated using multiple linear regression analysis with equation as

$$Y_1 = b_0 + b_1X_1 + b_2X_2 + \text{——} + b_8X_8$$

Where,

Y_1= disease severity (%), b_0=constant and b_1 to b_8 were the regression co-efficient of X_1 to X_8, respectively. X_1 =max. temp. (ºC), X_2= min. temp. (ºC), X_3 = morning RH (%), X_4= evening RH (%), X_5= rainfall (mm), X_6 = wind velocity (kmph), X_7=evaporation (mm/day) and X_8 = sunshine h/day.

C. Disease prediction models

The 2^{nd} degree polynomial model was used to find out the suitable estimate for the disease progression.

$$Y_x = a + b_1x + b_2x^2$$

Where,

a and b_1 were intercept and regression coefficients, respectively,

Y_x indicated expected disease severity at time x of seven days interval.

RESULTS AND DISCUSSION

The epidemiological studies are divided into two groups, one based on the effect of as many variables as possible of the host, pathogen and environment and the other where only the key variables involved in disease development. The relationship between various environmental factors were recorded on the disease development at different dates of sowing and detailed here under.

A. Weather parameters during the disease assessment period

The data on the weather parameters showed considerable variations with respect to weekly means. The maximum temperature during 2016-17was 28.28°C (52 SMW) to 37.86°C (13 SMW) and in 2017-18 it was 27.29°C (2 SMW) to 32.28°C (12 SMW); minimum temperature was 15.68°C (3 SMW) to 26.07°C (13 SMW) in 2016-17 and during 2017-18 it was 18.00°C (49 SMW) to 24.71°C (13 SMW); morning relative humidity was 69.41 (13 SMW) to 92.85% (5 SMW) and from 82.86 (49 SMW) to 90.14% (12 SMW) during 2016-17 and 2017-18, respectively. Evening relative humidity was 37.71 (3 SMW) to 77.57% (50 SMW) in 2016-17 and 71.00 (7 SMW) to 76.43% (47 SMW) during 2017-18. Rainfall occurred two times 10.60 mm on 48 SMW and 2.60 mm on 50 SMW during 2016-17 and five times 1.40 mm to 10.30 mm between 46 SMW to 1^{st} SMW during 2017-18 in the disease assessment period. The range of wind velocity, evaporation and sunshine hours were 1.05 (45 SMW) to 5.57 (12 SMW), 0.22 (3 SMW) to 3.32 (48 SMW), 2.28 (1 SMW) to 4.08 (12 SMW) and 2.40 (4 SMW) to 4.37 (48 SMW), 2.47 (52 SMW) to 9.04 (7 SMW and 2.43 (46 SMW) to 8.89 (9 SMW) during 2016-17 and 2017-18, respectively. The weather parameters particularly, maximum and minimum temperature, morning and evening relative humidity and rainfall showed considerable variations and the remaining independent variables showed ±1 variation (Table 1).

B. Effect of dates of sowing on the disease development

Severity of field bean anthracnose was significantly influenced by dates of sowing. The data showed that PDI increased gradually and progressed up to harvesting stage. Crop sown in 26^{th} September showed less terminal PDI of 39.40 and 45.53 during 2016-17 and 2017-18, respectively, and increased in the subsequent dates of sowing during both the years (Table 2). The reason for high disease severity with the advancement of sowing dates is due to exposure to favourable weather and availability of inoculum for disease development.

In different dates of sowing, early infection was noticed in late sown crop (*i.e.*, 31^{st} October) of about 21 days after sowing (DAS) and this was followed by the fourth and fifth sowings, where the infection appeared 28 DAS and late infection was observed in the early sown crop (42 DAS) of first and second sowing during 2016-17. Similarly during 2017-18 early infection was noticed in late sown crop (*i.e.*, 31^{st} October) of about 17 DAS and this was followed by the fourth and fifth sowings where the infection appeared 24 DAS and late infection was observed in the early sown crop (38 DAS) of first and second sowing during 2016-17. Two years data suggested that early infection of about 5-7 days occurred during 2017-18 irrespective of same dates of sowings as compared to during 2016-17. The first appearance of anthracnose symptoms was noticed at 42 DAS in 2016-17 and 38 DAS in 2017-18 and diseases progressed thereafter (Table 2).

Table 1: Weekly weather parameters during the crop seasons of field bean (2016-17 and 2017-18).

Weather parameters		2016-17		2017-18	
		Range	Mean	Range	Mean
X_1	Maximum temperature (^oC)	28.28 (52 SMW) to 37.86 (13 SMW) **	31.41	27.29 (2 SMW) to 32.28 (12 SMW)	29.60
X_2	Minimum temperature (^oC)	15.68 (3 SMW) to 26.07 (13 SMW)	20.16	18.00 (49 SMW) to 24.71(13 SMW)	21.34
X_9	Mean temperature (^oC)	23.23 (3 SMW) to 31.97 (SMW)	25.79	23.29 (49 SMW) to 28.14 (13 SMW)	25.48
X_3	Morning relative humidity -1 (%)	69.41 (13 SMW) to 92.85 (5 SMW)	85.57	82.86 (49 SMW) to 90.14 (12 SMW)	85.27
X_4	Evening relative humidity-II (%)	37.71 (3 SMW) to 77.57 (50 SMW)	55.88	71.00 (7 SMW) to 76.43 (47 SMW)	72.67
X_{10}	Mean Relative humidity (%)	56.96 (13 SMW) to 80.71 (46 SMW)	70.73	77.14 (9 SMW) to 82.26 (47 SMW)	78.98
X_5	Average rainfall (mm)	0.00 to 1.51 (48 SMW)	0.10	0.00 to 1.50 (48 SMW)	0.15
X_6	Wind velocity (kmph)	1.05 (45 SMW) to 5.57 (12 SMW)	3.51	0.22 (3 SMW) to 3.32 (48 SMW)	1.61
X_7	Evaporation (mm/day)	2.28 (1 SMW) to 4.08 (12 SMW)	3.37	2.40 (4 SMW) to 4.37 (48 SMW)	3.37
X_8	Sunshine hours (h/day)	2.47 (52 SMW) to 9.04 (7 SMW)	6.67	2.43 (46 SMW) to 8.89 (9 SMW)	6.38
	Total rainfall (mm)	0.00 to 13.20	0.68	0.00 to 21.60	0.98
SMW** Standard Meteorological Week					

Table 2: Effect of weather parameters and dates of sowing on the development of field bean anthracnose during 2016-17 and 2017-18.

Meteorological week	2016-17						2017-18					
	26.09.16 (First sowing)*	03.10.16 (Second sowing)*	10.10.16 (Third sowing)*	17.10.16 (Fourth sowing)*	24.10.16 (Fifth sowing)*	31.10.16 (Sixth sowing)*	26.09.17 (First sowing)*	03.10.17 (Second sowing)*	10.10.17 (Third sowing)*	17.10.17 (Fourth sowing)*	24.10.17 (Fifth sowing)*	31.10.17 (Sixth sowing)*
44	0.00	0.00	0.00	0.00	0.00	0.00	1.35	0.00	0.00	0.00	0.00	0.00
45	1.95	0.00	0.00	0.00	0.00	0.00	2.25	2.73	3.23	2.35	0.00	0.00
46	2.50	2.75	3.05	2.79	0.00	0.00	3.35	3.51	3.75	3.35	3.06	2.45
47	3.25	3.20	4.24	3.54	4.93	4.70	4.50	4.45	5.25	4.49	4.21	3.95
48	4.30	4.48	5.54	4.55	6.58	6.25	6.10	5.69	6.75	6.25	6.08	5.75
49	5.58	6.17	7.06	5.95	8.51	8.32	8.05	6.95	8.55	8.12	7.95	8.15
50	7.43	7.95	8.95	7.50	10.50	10.75	9.95	8.25	10.52	10.25	9.95	10.75
51	9.43	9.89	11.25	9.25	12.50	13.54	11.95	9.95	12.50	12.75	12.02	13.50
52	11.50	12.12	13.75	11.25	14.95	16.24	13.95	11.95	14.50	15.25	14.25	16.45
1	13.65	14.75	16.25	13.59	17.95	19.25	16.05	14.25	16.75	17.95	16.96	19.50
2	15.95	17.45	19.15	16.58	21.25	23.25	18.25	16.60	19.55	20.85	19.95	22.75
3	18.45	20.25	22.45	19.58	24.75	27.25	20.75	19.63	22.45	24.25	23.15	26.35
4	20.95	23.14	26.35	23.25	28.50	31.50	23.54	24.55	25.45	28.45	26.58	30.75
5	24.25	26.25	30.35	26.96	32.42	36.45	27.75	30.21	30.25	33.75	32.45	36.75
6	28.45	30.45	35.45	32.25	37.85	41.25	31.25	33.45	34.45	37.85	36.78	41.25
7	31.45	33.58	39.45	36.45	42.25	45.25	34.45	35.95	38.45	41.35	40.25	44.25
8	33.56	36.25	42.25	40.25	45.25	48.25	37.45	38.45	41.25	43.55	42.58	46.25
9	35.45	38.25	44.25	43.25	47.25	50.25	39.45	40.75	43.45	45.45	45.25	47.95
10	36.95	39.45	45.25	45.25	48.50	51.75	41.35	43.00	45.25	47.25	47.58	49.25
11	37.95	40.50	46.25	46.95	49.50	53.24	42.85	45.02	46.25	48.45	49.25	50.25
12	38.50	41.50	47.25	47.95	50.25	54.25	44.25	46.25	47.15	49.45	50.25	51.25
13	39.40	42.33	47.84	48.48	50.94	55.38	45.53	47.25	47.95	49.89	51.25	51.54
*Mean of four replications												

Initial PDI was more except in 10th October sowing during 2016-17 as compared to 2017-18 in all the sowing dates. But PDI at 47th SMW was more during 2017-18 as compared to 2016-17 (in early sowing dates and mid sowing dates) as initial disease appeared earlier (about 5-7 days) in 2017-18 than in 2016-17. It may be due to the early infection or pathogen survival in plant debris as well as polycyclic nature of pathogen. These results are in accordance with the findings of Tu (1983) and Dillard and Cobb (1993), who reported that pathogen survives in infected plant debris, pods and seeds at least 5 years. Further it was noticed that PDI increased with age of crop due to secondary spread achieved by conidia which are disseminated by wind.

Progress of disease slightly increased from first week of November to last week of January or first week of February in both years due to congenial weather conditions *viz.*, temperature, relative humidity, rainfall and frequency of rains as was evident from periodic disease progress recorded. During this period mean maximum temperature was 30.02°C, mean minimum temperature was 19.06°C, mean morning relative humidity was 87.39%, mean evening relative humidity was 60.78%, cumulative rainfall ranged from 0.0 to 13.20 mm with an average of 0.13 mm during 2016-17 and while mean maximum temperature was 28.97°C, mean minimum temperature was 21.19°C, mean morning relative humidity was 84.70%, mean evening relative humidity was 73.21%, cumulative rainfall ranged from 0.0 to 21.60 mm with an average of 0.22 mm during the year 2017-18 (Fig. 1).

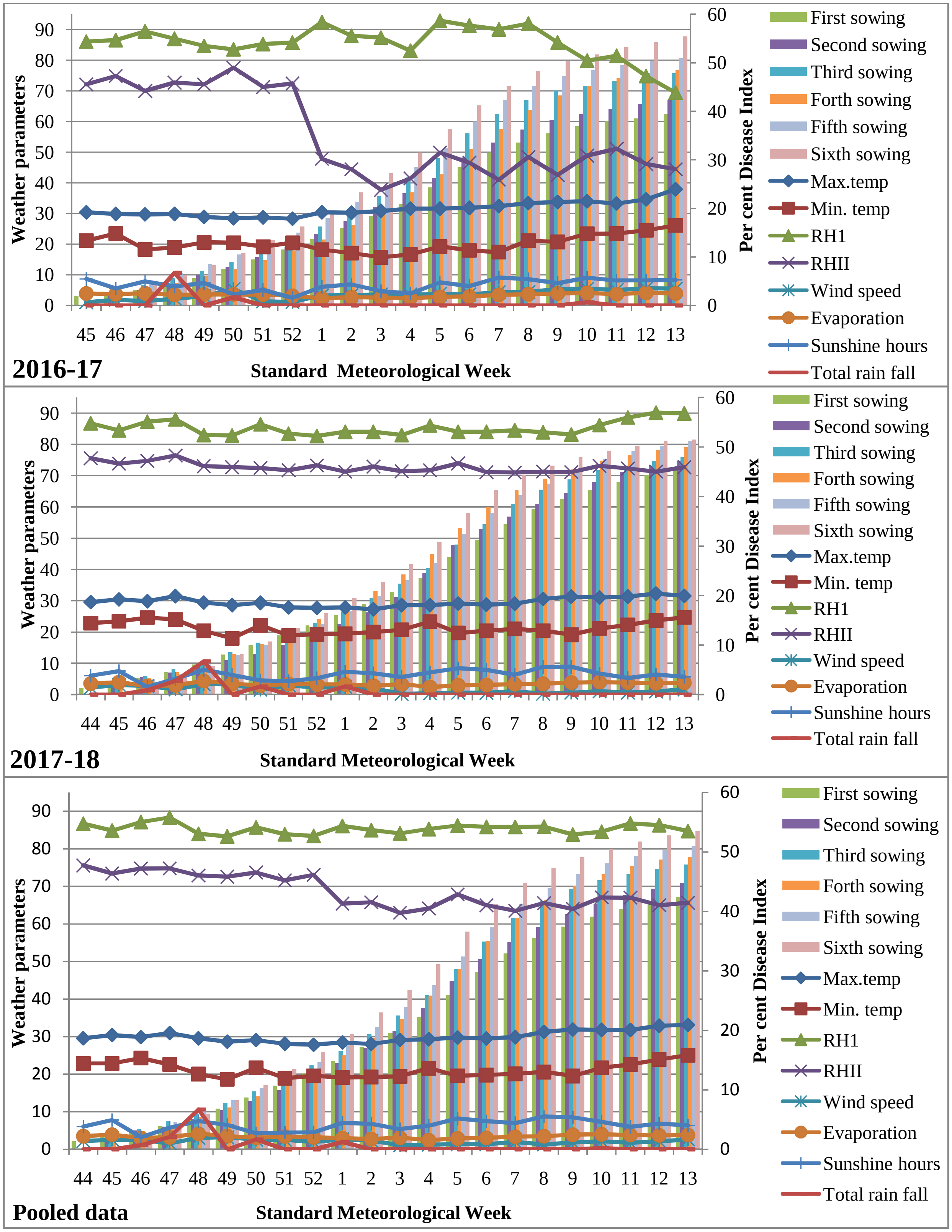

Fig. 1. Effect of weather factors in relation to field bean anthracnose at different dates of sowing.

Comparatively, mean weekly increase in PDI was higher from 3rd SMW to 6th SMW and 3rd SMW to 5th SMW during 2016-17 and 2017-18, respectively, than that of other disease assessment weeks. This indicates, elevation of temperature, above 27ºC from November, coupled with frequent rains that received during this period were preponderant conditions for the anthracnose progress. These results are in accordance with Yesuf and Sangchote (2007) and Kumar *et al.* (1999), who reported that frequent showers, particularly those accompanied by driving winds and cool temperature, highly favoured disease development in common bean.

Per cent disease index of field bean anthracnose at different dates of sowing during 2016-17 ranged from 1.95 to 39.40, 2.75 to 42.33, 3.05 to 47.84, 2.79 to 48.48, 4.93 to 50.94 and 4.75 to 55.38 in first, second, third, fourth, fifth and sixth dates of sowing, respectively. Similarly during 2017-18, PDI ranged from 1.35 to 45.53, 2.73 to 47.25, 3.23 to 47.95, 2.35 to 49.89, 3.06 to 51.25 and 2.45 to 51.54 in first, second, third, fourth, fifth and sixth dates of sowing, respectively. Mean minimum temperature, mean evening relative humidity, mean relative humidity, cumulative rainfall and average rainfall were less in 2016-17 as compared to 2017-18. Similarly mean maximum temperature and wind velocity were high in 2016-17 as compared to 2017-18 but no such difference was noticed with respect to mean temperature, 25.79°C and 25.48°C, mean morning relative humidity, 85.57 and 85.27%, mean evaporation, 3.37 and 3.37 mm/day and sunshine hours, 6.67 and 6.38 h/day in 2016-17 and 2017-18, respectively. The PDI in different dates of sowing was more during 2017-18 as compared to 2016-17 (Fig. 1). This may be due to the inoculum present in the previous season crop and also congenial weather conditions for disease development during the year 2017-18.

The disease progressed at linear pattern up to 6th SWM *i.e.*, first week of February with 4.20 per cent in first and second sown crops during 2016-17 and thereafter declined gradually due to raise in the temperatures. Same trend was noticed during 2017-18 also with weekly increase of PDI between 4.21 and 6.00. Hence, 16th January to 9th February may be considered as window period for field bean anthracnose for entire season in different dates of sowing. During this period, mean maximum, minimum temperature, mean morning relative humidity and evening relative humidity were 31.43°C, 17.36°C, 88.67% and 43.69% during 2016-17 and 28.75°C, 21.03°C, 84.25% and 72.03% during 2017-18, respectively (Fig. 2).

The mean weekly increase of PDI was highest (4.20, 4.20, 5.10, 5.29, 5.43 and 4.80) at 6th meteorological week where minimum and maximum temperatures were (20.40°C and 28.71°C), morning and evening relative humidity were (84.00 and 71.10%), respectively, in 29th September, 3rd, 10th, 17th, 24th and 31st October sown crops during 2016-17 (Fig. 2). Similarly, the mean weekly increase in PDI was highest (4.21, 5.66, 4.80, 5.30, 5.87 and 6.00) at 5th meteorological week where minimum and maximum temperature were (19.70°C and 29.14°C), morning and evening relative humidity were (84.00 and 73.90%), respectively, in 29th September, 3rd, 10th, 17th, 24th and 31st October sown crops during the year 2017-18 (Fig 2). These results are in accordance with Udaykumar and Usha (2010) who reported that temperature of 25°C was good for disease development.

The weekly decrease in progress of PDI after 7th SMW (16th February) coincided with absence of rainfall and gradual increase in temperature with maximum values above 30ºC. These conditions occurred in 2nd week of February with a steep fall in the anthracnose progress curve, provided an unfavorable environment for the disease (Fig. 2) and corroborate that temperature had limiting effect on disease progress curve, confirming observations made by Rahe and Kuae (1970).

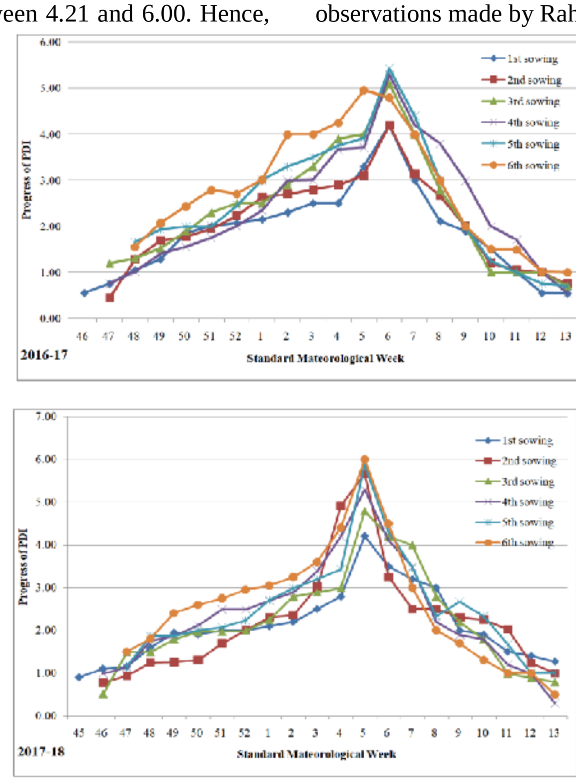

Fig. 2. Progress of per cent disease index of field bean anthracnose at different dates of sowing.

The rate of disease development gradually increased from November to February and thereafter it declined gradually. This indicated relationship between PDI with meteorological factors individually or jointly. Hence, the data was subjected to statistical analysis for finding out their effect on the disease development.

C. Simple correlation between the weather variables and disease severity of anthracnose in different dates of sowing

Correlation co-efficient revealed that, PDI was significant and positively correlated with maximum temperature (0.862 to 0.892), mean temperature (0.651 to 0.723), wind velocity (0.817 to 0.824) and sunshine hours (0.454 to 0.496) whereas significant negative correlation was observed with evening relative humidity (0.798 to 0.753) and mean relative humidity (0.855 to 0.836). Non significant negative correlation was observed with morning relative humidity (0.413 to 0.354) and rainfall (0.285 to 0.265) and non significant positive correlation was noticed with minimum temperature (0.323 to 0.416) and evaporation (0.121 to 0.215) irrespective of sowing dates during 2016-17. Regression analysis clearly depicted that maximum temperature, mean temperature, wind velocity and sunshine hours influenced the disease severity during 2016-17. With respect to the dates of sowing, crop sown on 17th October was highly influenced, whereas 31st October sown crop was less influenced by the individual weather parameters during the year 2016-17 (Table 3).

Table 3: Correlation between weather parameters and PDI of anthracnose at different dates of sowing.

Dates of sowing	Year	MAXI TEMP.	MINI TEMP	MEAN TEMP	RH I	RH II	MEAN RH	Rainfall	Wind velocity	Evaporation	Sunshine hours
26th Sept.	2016-17	0.877**	0.366	0.685**	-0.375	-0.783**	-0.849**	-0.284	0.817**	0.158	0.474*
	2017-18	0.461*	0.010	0.225	0.303	-0.584**	-0.060	-0.404	-0.719**	0.240	0.354
Pooled		0.766**	0.179	0.498*	-0.315	-0.801**	-0.844**	-0.468*	0.421	0.173	0.500**
3rd Oct.	2016-17	0.873**	0.356	0.677**	-0.374	-0.790**	-0.855**	-0.282	0.822**	0.142	0.459*
	2017-18	0.489*	0.040	0.258	0.32	-0.559**	-0.036	-0.396	-0.724**	0.242	0.364
Pooled		0.784**	0.186	0.506*	-0.304	-0.800**	-0.840**	-0.463*	0.413	0.170	0.506*
10th Oct.	2016-17	0.872**	0.353	0.675**	-0.362	-0.784**	-0.845**	-0.277	0.818**	0.152	0.467*
	2017-18	0.461*	0.002	0.220	0.286	-0.588**	-0.075	-0.399	-0.725**	0.240	0.366
Pooled		0.772**	0.165	0.488*	-0.295	-0.804**	-0.841**	-0.466*	0.413	0.170	0.507*
17th Oct.	2016-17	0.892**	0.416	0.723**	-0.413	-0.753**	-0.836**	-0.265	0.824**	0.215	0.496*
	2017-18	0.434*	0.009	0.201	0.269	-0.596**	-0.092	-0.409	-0.743**	0.212	0.379
Pooled		0.783**	0.184	0.505*	-0.304	-0.797**	-0.837**	-0.461*	0.417	0.181	0.509*
24th Oct.	2016-17	0.863**	0.331	0.656**	-0.357	-0.790**	-0.848**	-0.268	0.823**	0.140	0.463*
	2017-18	0.455*	0.005	0.219	0.296	-0.581**	-0.064	-0.397	-0.730**	0.228	0.358
Pooled		0.767**	0.155	0.479*	-0.298	-0.807**	-0.844**	-0.458*	0.416	0.162	0.505*
31st Oct.	2016-17	0.862**	0.323	0.651**	-0.354	-0.798**	-0.854**	-0.277	0.818**	0.121	0.454*
	2017-18	0.401**	0.033	0.169	0.246	-0.608**	-0.115	-0.415	-0.757**	0.184	0.387
Pooled		0.743**	0.121	0.477*	-0.273	-0.825**	-0.855**	-0.412	0.387	0.121	0.502*

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

During 2017-18, PDI showed significant positive correlation with maximum temperature (0.401 to 0.489), whereas significant negative correlation was observed with evening relative humidity (0.608 to 0.559) and wind velocity (0.757 0.719). Non significant negative correlation was observed with mean relative humidity (0.115 to 0.036) and rainfall (0.40 to 0.397), while minimum temperature (0.002 to 0.10), mean temperature (0.169 to 0.258), morning relative humidity (0.246 to 0.320), evaporation (0.184 to 0.242) and sunshine hours (0.354 to 0.387) expressed non significant positive correlation, irrespective of sowing dates. Regression analysis showed that, among the weather factors maximum temperature, morning relative humidity and sunshine hours influenced the disease severity. With respect to the dates of sowing, crop sown on 3rd October was highly influenced, whereas 31st October sown crop less influenced by the individual weather parameters during 2017-18 (Table 3).

In both years, significant positive correlation was noticed with maximum temperature, while evening relative humidity was negatively correlated; minimum temperature, sunshine hours and evaporation were non significant with positive correlation, while rainfall was non significant, negatively correlated with disease severity. These results were similar with the findings of Kulkarni and Benegi (2012) and Jaydeep *et al*. (2014), who reported positive correlations with maximum temperature, sunshine and evaporation and negative correlations with minimum temperature, mean temperature, morning relative humidity, evening relative humidity, mean relative humidity, rainfall and rainy days.

Significant positive correlation of PDI with maximum temperature and non significant positive correlation with minimum temperature was observed at all sowing dates in both years. As the temperatures (maximum and minimum) increased there was increase in PDI and with the increase of relative humidity (morning and evening) and rainfall there was decrease in PDI in both years. Thus, both temperatures played a major role in field bean anthracnose development. Similar results were reported by Kumar *et al*. (1999) on recurrence and development of French bean anthracnose in relation to weather variables.

However, there was intra correlation among the weather variables like rainfall with relative humidity as well as with minimum temperature in different dates of sowing. Hence the data is subjected to multiple correlations.

D. Multiple correlations between the weather variables and disease severity of anthracnose at different dates of sowing

Multiple correlations between the dependent variable (disease) and a group of eight independent (weather factors) variables responsible for the disease development under study were developed and found highly significant in both years at all the dates of sowing. Multiple correlation co- efficient during 2016-17 and 2017-18 indicated strong relationship between disease severity with weather variables, contributing more than 95.1 per cent during 2016-17 and 93.9 per cent variation in PDI during 2017-18 (Table 4).

Table 4: Multiple regression equations between per cent disease index and weather variables at different dates of sowing.

Dates of sowing	Year	Multiple correlation coefficient (R)	Co efficient of determination (R^2)	Adjusted R^2	Regression equation								
					A	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
26th Sept.	2016-17	0.957	0.916	0.860	-62.806	0.814	1.697	0.524	-0.790	0.114	1.729	7.735	-1.488
	2017-18	0.941	0.886	0.816	-71.146	0.413	-2.833	4.262	-3.374	-0.897	-6.581	7.813	1.305
	Pooled	0.943	0.889	0.821	-100.170	5.170	-1.533	0.470	-0.935	-0.957	3.731	5.946	-2.000
03rd Oct.	2016-17	0.959	0.919	0.865	-66.899	0.885	1.833	0.567	-0.859	0.138	1.999	8.146	-1.727
	2017-18	0.938	0.880	0.807	-88.415	0.833	-2.716	4.343	-3.451	-0.965	-7.010	7.867	1.641
	Pooled	0.942	0.888	0.819	-125.050	6.042	-1.728	0.538	0.935	-0.983	3.825	5.225	-2.065
10th Oct.	2016-17	0.956	0.914	0.857	-93.588	1.313	1.954	0.730	-0.953	0.155	2.333	9.983	-2.016
	2017-18	0.939	0.882	0.809	-49.792	0.945	-2.930	4.191	-3.741	-0.944	-7.187	7.777	1.368
	Pooled	0.943	0.888	0.820	-140.770	6.401	-2.073	0.733	-1.051	-1.112	4.455	7.072	2.464
17th Oct.	2016-17	0.961	0.924	0.873	-83.596	0.977	2.269	0.628	-0.993	0.263	2.173	10.828	-1.833
	2017-18	0.939	0.882	0.809	-50.108	0.462	-3.020	4.518	-3.902	-1.024	-8.104	8.240	1.679
	Pooled	0.943	0.889	0.820	-144.475	6.535	-1.919	0.716	-1.095	-1.120	4.439	7.252	-2.447
24th Oct.	2016-17	0.951	0.905	0.841	-86.019	1.350	1.728	0.682	-0.981	0.169	2.825	10.308	-1.976
	2017-18	0.939	0.882	0.810	-87.003	0.496	-3.421	4.990	-3.868	-0.957	-8.210	8.939	1.515
	Pooled	0.940	0.884	0.813	-143.490	7.073	-2.395	0.672	-1.110	-1.101	4.936	6.752	-2.614
31st Oct.	2016-17	0.951	0.904	0.839	-94.917	1.648	1.860	0.723	-1.039	0.097	2.955	10.124	-2.146
	2017-18	0.939	0.883	0.810	-50.902	0.017	-3.406	4.937	-4.071	-1.031	-9.123	8.422	1.854
	Pooled	0.937	0.878	0.802	-131.957	7.214	-2.493	0.660	-1.239	-1.172	4.604	6.154	-2.545

X_1: Maximum temperature; X_2: Minimum temperature; X_3: Morning relative humidity; X_4: Evening relative humidity; X_5: Rainfall; X_6: Wind velocity; X_7: Evaporation; X_8: Sunshine hours.

Regression equations computed for predicting unit increase/decrease in disease showed that different weather variables could influence progress of disease development to a given extent in positive direction if weather conditions prevail in an area over a specified period of time.

Multiple regression co-efficient of disease severity with maximum temperature was positive in 2016-17 (0.814 to 1.648) and in 2017-18 (0.017 to 0.945) in all the dates of sowing, while minimum temperature was positive during 2016-17 (1.697 to 2.269) and negative during 2017-18 (3.421 to 2.716). Morning RH was positive in both years (0.524 to 0.730 in 2016-17 and 4.191 to 4.990 in 2017-18) and evening RH was negative in both years (1.039 to 0.790 in 2016-17 and 4.071 to 3.374 in 2017-18), at all the dates of sowing, except in 17th October sown crop with positive influence of evening relative humidity during 2016-17. Other weather parameters like rain fall, wind velocity, evaporation showed positive influence, while sunshine hours were negative during 2016-17; rainfall and wind velocity showed negative influence, whereas evaporation and sunshine hours were positive during 2017-18 at all the dates of sowing. The co-efficient of determination (R^2) revealed that weather variables contributed towards the PDI ranging from 90.40 - 92.40 per cent variation during 2016-17 and 88.00-88.60 per cent variation during 2017-18. During 2016-17, the co-efficient of multiple determinants (R^2) was 0.924 indicating 92.40% of variation in anthracnose development explained by the set of variables studied in 17th October sown crop (Table 4). These results to a greater extent corroborate the findings of Gupta and Sharma (2009) who reported the multiple correlation coefficients between disease severity and group of independent variable was found to be 0.6194 which indicates that 61.94 per cent change in disease severity was caused by mean air temperature, relative humidity and cumulative rainfall collectively.

The R^2 values indicated that the combination of eight weather factors accounted for variation in disease development to the extent of 88.6-91.6, 88.0-91.9, 88.2-91.4, 88.2-92.4, 88.2-90.5 and 88.3-90.4 per cent in first, second, third, fourth, fifth and sixth sowings, respectively, during 2016-17 and 2017-18 (Table 4). The analysis of all the eight independent variables individually and in combinations revealed the best fit for the disease development in addition to other unknown factors. In the present epidemiological study with different dates of sowings, progress of field bean anthracnose was affected by variation in weather variables as well as by their interactions. Similar findings in French bean, greengram and kidney bean were reported by Tu (1983) and Kumar *et al.* (1999).

The results pertaining to the effect of weather parameters at different dates of sowing were presented in Table 4 revealed that, among the different dates of sowing, weather factors highly influenced the disease severity in 17th October sown crop and caused variation to the extent of 92.4 per cent, while less influenced 31st October sown crop with 90.4 per cent variation, where the adjusted R^2 values were 87.3 and 83.9, respectively, during 2016-17. Similarly during 2017-18, weather factors highly influenced the disease severity with 88.60 per cent variation in 26th September sown crop and less influenced 10th October sown crop with 88.20 per cent variation of disease severity, where the adjusted R^2 values were 81.6 and 80.9, respectively.

Table 5: Predicted equations of anthracnose in field bean with different dates of sowing.

Year	Dates of sowing	Predicted equations	R	R^2	Adjusted R^2
2016-17	26th September	$Y=-2.556+1.821x+0.16X^2$	0.990	0.981	0.978
2017-18		$Y=-2.135+1.637x+0.031x^2$	0.995	0.989	0.988
Pooled		$Y=-2.677+1.613x+0.027x^2$	0.993	0.986	0.985
2016-17	3rd October	$Y=-4.892+2.345x+0.003x^2$	0.992	0.983	0.981
2017-18		$Y=-3.213+1.601x+0.04x^2$	0.989	0.979	0.976
Pooled		$Y=-4.527+1.856x+0.026x^2$	0.991	0.982	0.980
2016-17	10th October	$Y=-5.561+2.676X+0.004x^2$	0.988	0.977	0.974
2017-18		$Y=-3.579+2.016x+0.024x^2$	0.991	0.981	0.979
Pooled		$Y=-5.109+2.201x+0.019x^2$	0.990	0.980	0.977
2016-17	17th October	$Y=-3.727+1.797x+0.044x^2$	0.990	0.979	0.977
2017-18		$Y=-6.324+2.606x+0.007x^2$	0.989	0.979	0.976
Pooled		$Y=-5.41+2.071x+0.029x^2$	0.990	0.980	0.978
2016-17	24th October	$Y=-8.138+3.342x-0.016x^2$	0.989	0.978	0.975
2017-18		$Y=-7.363+2.527x+0.015x^2$	0.992	0.983	0.981
Pooled		$Y=-8.838+2.836x+0.004x^2$	0.991	0.983	0.981
2016-17	31st October	$Y=-10.442+3.902x-0.028x^2$	0.991	0.982	0.980
2017-18		$Y=-12.446+3.788x-0.031x^2$	0.989	0.979	0.976
Pooled		$Y=-12.583+3.743x-0.025x^2$	0.991	0.982	0.980

E. Disease prediction models

Modelling provides a great deal of information regarding the amount and efficacy of the initial disease inoculum, the effects of environment, host resistance, the length of time for host and pathogen interaction and the effectiveness of various disease management strategies. Based on the results of multiple regression analysis, prediction equations were developed and fitted for different dates of sowing. Disease prediction models, based on meteorological data, help to predict when the disease will occur and to improve the use of control measures.

During 2016-17, among the different dates of sowing, crop sown on 3rd October had the highest coefficient of determination values with 98.4 per cent and less standard error of estimates (1.971). The equation is as follows:

$Y = -3.802 + 5.154X + 0.01X^2$ with $R^2= 0.984$ and SEE = 1.971

During 2017-18, among the different dates of sowing, crop sown on 26th September had the highest coefficient of determination (98.9%) and less standard error of estimates (1.661). The equation is as follows:

$Y = -2.135 + 1.637X - 0.031 X^2$ with $R^2= 0.989$ and SEE=1.661.

CONCLUSION

Plant disease is a dynamic process in time and space caused by the continuous irritation of a susceptible host due to a biotic or abiotic agent in a conducive environment which results in loss of crop or yield or both above economic threshold level. In the present it was concluded that, severity of field bean anthracnose was significantly influenced by different weather variables at different dates of sowing and January first two weeks were found favourable for initiation of disease.

The infection started at 46th SMW and attained its peak on completion of major portion of rainfall. Duration from 16th January to 9th February may be considered as window period for field bean anthracnose for entire season in different dates of sowing. Hence, it is necessary to implement various effective management strategies from 16th January to 9th February. Disease infection, development and spread are associated with weather factors. Temperature and humidity play an important role for the development of anthracnose infection. Among the different dates of sowings, second fortnight of October is the best period to obtain more yields with minimum management practices. The prediction model developed the study helps to forecast the disease so that chemicals could be applied economically and frequency of their application could be minimized to avoid environmental and health hazard effects.

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