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RESEARCH ARTICLE

Epidemiological Model based Decision Support System for the Management of Grapes Downy Mildew

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ABSTRACT

Grapevine downy mildew caused by *Plasmopara viticola* is an explosive disease that causes severe damage to leaf, flowers and fruits of the vine. In the present study, an epidemiological model was developed to support the vine-growers to reduce the number of fungicidal sprays and protect the environmental hazards besides saving the input cost. To record the weather data, an automatic weather station was installed at Mathampatti Village, Coimbatore, India and the weather parameters such as relative humidity, minimum, maximum and night temperatures, rainfall, leaf wetness, dew fall, solar radiation *etc*., were recorded at once in a 10 minutes interval during 2014-17. A logistic equation was designed based on the biological data (disease incidence, weather parameter and crop age) and its mathematical analysis was shown in this paper. The critical weather parameters were studied using logistic equation with the support of "Curve expert programme". The mode described the development of the infection and infection rate through computation-based analysis. The Decision Support Systems (DSS) were arrived using the disease progress curve obtained from the logistic equation. The DSS indicates the first two sprays during the congenial phase of the disease from 25 to 45 Days After Pruning (DAP). Then the second phase, ie rapid growth stage was termed as 'Exponential phase', in which two sprays on 55 and 65 DAP (flowering and fruiting stage) were carried out. In the final plateau phase (66 DAP to till harvest), the management strategies applied would not be cost-effective and no spray was recommended. The field experiment was carried out using the findings of the logistic equation with different management modules for validation. The number of sprays of fungicide was reduced from 15 to 5 times in the logistic equation-based treated plot.

Keywords: *Grapevine downy mildew; logistic model; weather index; azoxystrobin*

INTRODUCTION

The grapevine downy mildew caused by *Plasmopara viticola* is one of the destructive diseases of grapevine, which causes complete loss in uncared vineyards. Under favorable conditions, losses due to premature defoliation and berries spoilage can reach 50-100 % (Gaforio *et al.,* 2015). Karthick *et al.* (2019) reported that downy mildew disease causes extensive yield loss by affecting all the green tissues of grapevine, including leaves, inflorescence and clusters. Due to the disease pressure, the vine-growers are forced to intervene indiscriminately with chemical treatments repeatedly in order to avoid yield losses. As a result of the frequent sprayings, the fungicide residues have been increased, which is not really warranted (Seem *et al*., 1985). The sexual stage of the pathogen *viz.,* oospores is the primary source of inoculum for initial infection season (Galbiati and Longhin, 1984). Followed by primary infection, successive asexual cycles (Blaeser and Weltzien, 1979) are responsible for the explosion of the disease under favorable environmental conditions. Sometimes primary and secondary infections overlap for part of the season.

Lalancette, (1988) developed a qualitative model for ascertaining the sporulation of sporangia for disease progress of *P. viticola* in grapes. The model suggested that the downy lesion was produced after 12hr at 20 °C. In order to ascertain high-risk periods for primary infections and time of fungicidal sprays, several weather-driven models have been proposed in different countries (Tran Manh Sung *et al*., 1990;

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Hill, 2000; Park *et al*., 1997). A new machine learning algorithms model for predicting the probability of high incidence was developed by Chen *et al*. (2020) and proposed the risk of grapes downy mildew at bunch maturity stage due to rainfall and temperatures in Bordeaux region of south western France. An advantage of this mathematical tool is the intrinsic relationship with other tools like disease progress curves and computer simulations because important components of disease dynamics can be modelled by using growth models that latter could be linked and simulated using computer programs (Mersha and Hau, 2008). The epidemic model made several simplifying assumptions and decisions, including logistic growth of the disease epidemic and dispersal of inoculum. The thumb rule for sporangia germination and lesion development supported the surveillance programme (Parnell *et al*., 2015). In this background, the aim of the present work was (i) to develop a mathematical model that would qualitatively describe the disease progress and its rate of increase to develop the decision support system and (ii) the application of the DSS in the crop protection program to avoid repeated spraying with fungicides without increasing the severity of downy mildew.

MATERIAL AND METHODS

Installation of automatic weather logger in grape vineyard

A mini data logger with seven probes for recording weather parameters *viz.,* temperature, relative humidity, soil moisture, soil temperature, solar radiation, leaf wetness and dewness was purchased and installed in the grapevine (Fig.1) yard as shown in the given figure. The data logger of automatic weather station recorded the weather data at 10 minutes intervals continuously and the data were stored in the memory module.

Stored data was downloaded at weekly intervals in to the computer system from the module and used for relating the weather data with disease incidence and appearance. The soil moisture data was calibrated by using the software and soil temperature was also recorded. (Sendhilvel, 2003)

Disease incidence

In an established grape vineyard with Muscat variety, the trials were laid out in a plot size of 30 x 6 m^2 (30 vines). The plot was maintained without fungicide spray during the growing season so as to observe the real downy mildew development. To identify the oil spot symptom, the third or fourth leaf in a vine was marked separately by using a label and 75 leaves were marked for replication. Then the oil spot symptom was noticed for further disease development and was scored by using the scale 1-9 and percent disease index was calculated (Nagarajan and Murlidharan, 1995)

Mathematical model analysis

The downy mildew disease progression was analyzed by fitting different disease progress models v*iz.,* Gompertz, Logistic and monomolecular model. The fitness of each model to downy mildew was assessed by using the Curve Expert 1.3 programme. The best fit was decided based on minimum standard error and maximum regression co - efficient. The equations of several models used in the analysis are given below. (Jones, 1998).

(Y)	$= ae^{-eb-cx}$	Gompertz model
(Y)	$=a/1+be^{-C.X}$	Logistic equation
(Y)	$= ab+cx^d$ $b+x^d$	Monomolecular
Where,		

Where,

a,b,c,d = Parameters to be estimated

X = Interval of observation in days.

Y = Amount of disease

Infection rate

The infection rate of downy mildew was calculated from the suitable model. The differential equation of the model gives the rate of infection of the disease. The software viz, Curve Expert was used to calculate the rate of infection. The differential equations are given below.

Name of the model	Infection rate Equation
Logistic model	(dy/dx) = r(k-y)
Gombertz model	(dy/dx) = ry(1-y/k)
Monomolecular Function	(dy/dx) = ry(In(k)-In(y)

Where,

r – rate of disease increase for the specific model

y – disease at the time of observation

k - constant

Input variables and parameters estimation

The model requires daily weather data like temperature, relative humidity, dew, sunshine and precipitation. The weather data were collected five days prior to disease observation. The correlation and regression analysis was carried out statistically. The available biological data (downy mildew infection and crop age) and weather factors were used to calculate the parameters of mathematical equation such as a, b and c and d. Then based on the parameters, estimated infection and infection rate were computed using the software "Curve expert" by the method and decision support system was developed based on the disease progress curve.

Field application of the model

The logistic model was simulated based on the critical weather factors and crop age along with disease incidence. The decisions were made from the curve and were applied for the disease management programme to determine the time of application. In an established vineyard with cv. Muscat, trials were laid out in a randomized block design (RBD) with four replications by maintaining a plot size of 6 x 5 m^2 (6 vines/plot).

The integrated management strategy was developed for the control of grapes downy mildew using the potential biocontrol agent *Pseudomonas fluorescens* (Talc based formulation Pf1). The developed DSS strategy was used to validate the model under field condition. The treatment structure for the validation cum On Farm Testing (OFT) of weather based forecasting model for downy mildew of grapes and its management are as follows:

Treatment	Description of module
Treatment I	FYM application at 20 kg/vine after pruning *Pseudomonas fluorescens* Pf1 application along with FYM at 100g/vine Foliar spray with Pf1@0.5% on 25, 35, 45, 55 and 65 DAP
Treatment II	FYM application at 20kg/vine Pf1 application along with FYM at 100g/vine Foliar spray with azoxystrobin@1ml/lit on 25, 35, 45, 55 and 65 DAP
Treatment III	FYM application at 20kg/vine Pf1 application along with FYM at 100g/vine Foliar spray with Pf1 @0.5% on 25, 45, and 65 DAP Foliar spray with Azoxystrobin @1 ml/lit on 35, and 55 DAP
Treatment IV	Farmers' practices
Treatment V	Control

One of the treatments was left untreated with fungicide during the growing season to observe the real downy mildew development. One set of plot (3 replications) was treated with a systemic fungicide *viz.,* azoxystrobin on the basis of the results of the growth model. The farmer's practices ie spraying of fungicides on their own viz., Mancozeb, Triadimefon, Zineb, Copper oxy chloride, Cymoxanil (2 times), Metalxyl (3 times) and Bordeaux mixture (3 times) which include spraying of fungicides to control the downy mildew were also evaluated as one of the treatment

During the field experiment, weather data were collected from AWS Meteorological station at Mathampatti Village.

Leaf area damaged by downy mildew was classified into five classes (0, 1-25, 26-50, 51-75, 76-100 percentage of leaf tissue infected) and the final value of PDI was computed by means of Mc Kinney's formula (Goidanich, 1959)

$$PDI = \frac{\text{Sum of all numerical ratings}}{\text{Total number of leaves observed}} \times \frac{100}{\text{Maximum grade in the score chart}}$$

RESULTS AND DISCUSSION

The mathematical models *viz.,* Gompertz, Logistic, monomolecular and Richard models were tested with constructed weather index and the results are presented in Table 1.

It was found that logistic model was suitable which recorded minimum standard error and maximum regression coefficient. The results showed that the logistic model recorded the maximum regression co efficient of 0.9972, 0.9972 and 0.9976 for relative humidity, dew and leaf wetness, respectively. Hence, this model was selected for the study of downy mildew disease progress growth. The Infection rate (Fig 3) and estimated infection (Fig 4) was calculated using logistic model equation. The appropriate model was studied by Van der Plank (1963) for polycyclic diseases and the logistic model was suitable for the secondary spread of the diseases within a growing season (Nutter, 2007). This growth model is the most widely used for describing epidemics of various plant disease (Segarra *et al.*, 2001; Jeger, 2004).

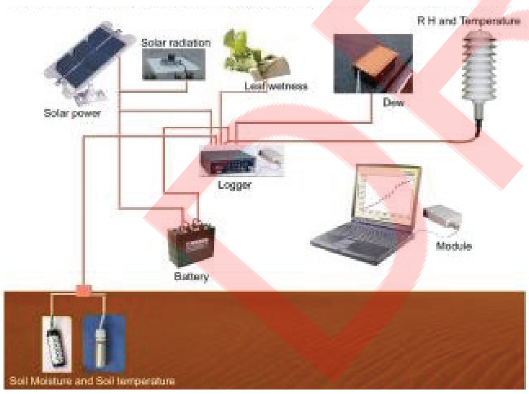
DECISION SUPPORT SYSTEM

The logistic curve was drawn to study the role of relative humidity and dew for downy mildew infection and presented in Fig 2. The disease growth is of

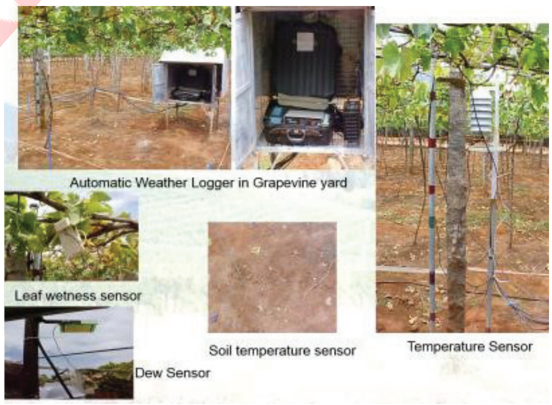
Table1. Analysis of weather index using different mathematical models

Weather Index	Mathematical model	Standard Error (S)	Regression co- efficient (R)
Relative humidity Index	Logistic model	**2.8311**	**0.9972**
	Richards model	2.8782	0.9946
	Gompertz model	3.8127	0.9949
	Monomolecular Function	7.3796	0.9825
Dew Index	Logistic model	**2.7914**	**0.9972**
	Richards model	2.7920	0.9955
	Gompertz model	3.8766	0.9947
	Monomolecular Function	7.3762	0.9826
Leaf wetness Index	Logistic model	**2.5685**	**0.9976**
	Richards model	2.6935	0.9946
	Gompertz model	3.2987	0.9961
	Monomolecular Function	6.6102	0.9860

sigmoid pattern. An epidemic grows as the extent of diseased tissue keeps on increasing over particular period of time. The Sigmoid curve has distinct stages separable from one another for polycyclic disease. In the initial stage, the growth curve is slow and runs parallel to horizontal (OX) axis and exhibits a tendency to gradually increase in logarithmic terms; this phase is mentioned as 'Congenial phase'. It is the ideal period for taking the management strategies which would reduce the growth rate of the epidemic (Fig 2 and 4). The second phase is rapid growth stage and the host substrate is not a limiting factor. This phase is mentioned as 'Exponential phase'. Fig 2 clearly showed that the infection rate increased up to 60 DAP (Exponential phase) and there after declined (Plateau phase). During the plateau phase, the management strategies applied may not be very efficient and cost-effective. (Sendhilvel, 2003)



Schematic flow chart of sensors



Installation of sensors with weather logger

From the curve, it is observed that the lag phase (Congenial phase) starts from 25 to 45 DAP with a PDI of 8.57 and ends with 20.29 . Based on the PDI from curve, the critical period for the lag phase was decided from the estimated infection data (Fig.4). Hence, the first spray was recommended on 25 DAP to contain the downy mildew infection during the congenial phase. Then, the subsequent two sprays were suggested at 10 days intervals *i.e.* 35 and 45 DAP. Three sprays were recommended in total till the completion of the lag phase.

Table. 2. Outcome of weather based Decision support system for the management of grapes downy mildew (Pooled analysis of five season trial)

Sl. No	Details of Treatment	Frequency of fungicide application	Downy mildew (PDI)*	Yield (Kg) / (6 vines/plot)	Cost Benefit Ratio
1	FYM application at 20 kg/vine after pruning Pf1 application along with FYM at 100g/vine Foliar spray with pf1@0.5% on 25, 35, 45, 55 and 65 DAP	5	17.6b (25.03)	73.41c (58.96)	4.1
2	FYM application at 20kg/vine Pf1 application along with FYM at 100g/vine Foliar spray with Azoxystrobin@1ml/lit on 25, 35, 45, 55 and 65 DAP	5	12.53a (20.72)	76.24d (60.83)	4.5
3	FYM application at 20kg/vine Pf1 application along with FYM at 100g/vine Foliar spray with Pf1 on 25, 45, and 65 DAP Foliar spray with Azoxystrobin on 35, and 55 DAP	5	12.56a (20.74)	75.01d (60.11)	4.6
4	Farmer's practices	15	28.50c (32.52)	68.62b (55.46)	3.3
5	Control		78.83d (62.76)	21.31a (27.48)	

Values are mean of three replications , Values in parenthesis are arc sine transformed values In a column, means followed by a common letter are not significantly different at the 5 % level by DMRT

In order to avoid the fruit infection, final two sprays were suggested during the exponential phase at 55 and 65 DAP. (Fruit setting coincides).

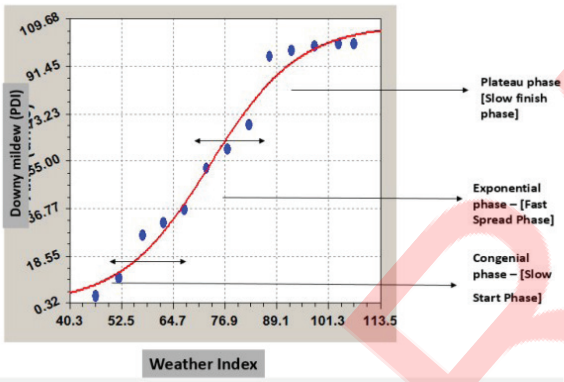


Figure 2. Logistic curve for the effect of Relative humidity on downy mildew of grapevine

The apple powdery mildew caused by *Podosphaera leucotricha* was forecasted using a logistic model (Xu, 1999).

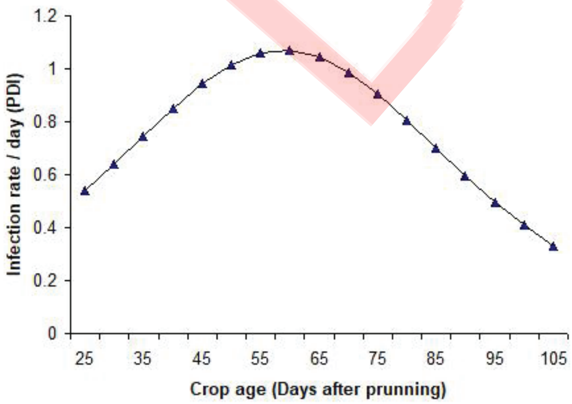


Figure 3. Estimated infection rate from logistic model

The Logistic and Gompertz models were used to study the disease progress for rust bean and its dynamics. The decision support system arrived to form the model was used to control the rust bean disease under greenhouse experiments with and without fungicide sprays.

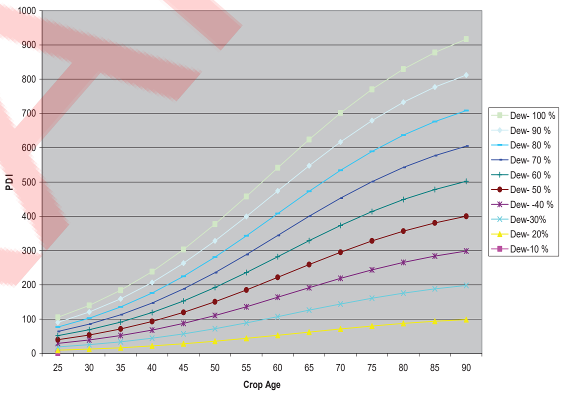


Figure 4. Estimated downy mildew infection at various level of dew

In our studies, the results obtained during the three year (five seasons) field experiment for logistic model validation provided good indications concerning the application of logistic model. The application of logistic model helped in reducing the number of sprayings (50 per cent) when compared to farmer's practices. The logistic model was able to adapt fungicide applications to the real infectious potentiality of each vineyard while with the farmer practices method (traditional method) the number of treatments was independent on the real risk of infection.

These benefits were obtained in this experiment and the disease incidence has been lowered

(Table 2). In fact significant difference (P>0.05) was found between the farmer practices (21.23 PDI) and the treatment combination which includes FYM application at 20kg/vine on the day after pruning, *Pseudomonas fluorescens* (Pf1) application along with FYM at 100g/vine, foliar spray with Pf1 on 25, 45, and 65 DAP, and foliar spray with Azoxystrobin on 35, and 55 DAP which recorded a disease intensity of 12.56 PDI and it was on par with plots treated with azoxystrobin alone (12.53). The cost benefit ratio was higher in the combination of *Pseudomonas fluorescens* (Pf1) @ 0.5 per cent and azoxystrobin @ 150 g a.i/ha (600 ml/ha) treated plot (1:4.6). The results clearly showed that that the above management strategy could be followed for effective control of downy mildew of grapevine.

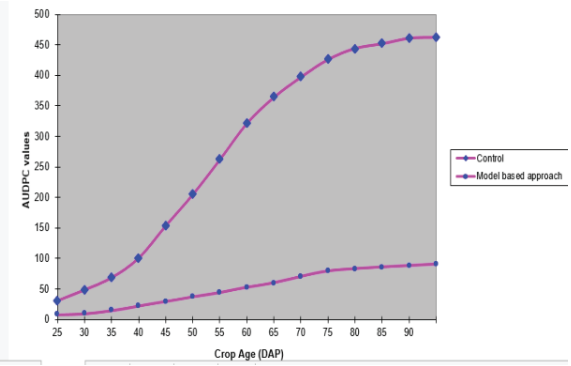


Figure 5. Area Under Disease Progress Curve (AUDPC) for grapes downy mildew disease

Similarly, in Italy a computer program was developed based on the biology of downy mildew and weather factors called as PLASMO. A two-year field experiment with this PLASMO model helped in reducing the number of fungicide application and also reduced the severity of downy mildew infection (Rosa *et al.,* 1995).

The management strategies adopted during lag phase effectively controlled the exponential phase of the disease and saved the crop from wheat rust disease (Nagarajan and Muralidharan, 1995). The spraying of fungicide based on the disease progress curves on potatoes to control the late blight disease was realized (Large, 1945 and 1952).

In our studies, the fitness of the logistic curve was shown to be the best model to develop the decision support system like the logistic growth model. Pearl and Reed (2006) explained the rate of disease increase could be a polynomial function of time, which gives suitable time for fungicide application. Van der Plank (1960) pointed out that the key components of disease progress were apparent in infection rate, initial inoculum and final disease level. Costa and Rosa (1998) developed PALM (*Plasmopara viticola* Artificial Life Model) model, which represented given phase of the life cycle of the pathogen. The age of the host (grapevine) was also considered in the PALM model. This simulated model reduced fungicide application for the management of grapevine downy mildew. Caffi *et al*. (2009) evaluated independent data, which represents many different epidemiological conditions and that neither calibration nor empirical adjustment of the model obtained accurate simulation (Rossi *et al*., 2008). The practical value of the disease prediction model achieved its probability of oospore that produces infection (Madden, 2006) 3 times higher than the prior probability, which shows the probability of the disease occurrence with higher accuracy. Considering Oosporic infection, which is contributing to disease epidemics over a large area of the particular season (Gobbin *et al*., 2005; Kennely *et al*., 2007), the model could also be applied for improved timing of sprays.

CONCLUSION

In the present study, the Decision Support System (DSS) was arrived at based on the logistic model disease growth curve, using Curve Expert 1.3 programme software for grapes downy mildew. The infection rate and stages of the infection were used to arrive at the weather-based DSS. While validating the DSS under field condition, the management measures applied during the congenial phase effectively controlled the grapes downy mildew and furthered the infection rate was contained. Our results clearly concluded that spraying of fungicides was found to be effective during the congenial or lag phase of the disease for grapes downy mildew.

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