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Role of modelling in plant disease management

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ABSTRACT

Indian's economy is agricultural based. Agriculture provides maximum employment in the country. Unfortunately, crop production is heavily affected by the pests and diseases. In addition to refinement in the existing management practices, there is a need for simulation models to assess the potential of emerging pathogens for a given crop production system and also shift in pathogen populations/fitness that may demand modifications in current production systems. Forecasting models which allows investigating multiple scenarios and interactions simultaneously has become most important for disease prediction, impact assessment and application of disease management measures. Many weather driven epidemiological models have been developed and used to predict plant disease epidemics under variable climate. Most forecasting models are meant for tactical and strategic decisions. Similarly, the Mill's Table also had been modified for Apple scab epidemic under H.P conditions. Moreover, remote sensing and image analysis have been used in plant diseases epidemiology to forecast the plant diseases. These epidemiological tools have been designed to help the farmers in enhancing the efficiency and adequacy of disease management. A complete knowledge of these epidemiological tools provide quick, fast and accurate prediction of disease and helps in timely disease control.

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Epidemiology:

The study of epidemics and of the factors that influence them is called epidemiology or the study of the rate of multiplication of a pathogen and spread of the disease in a plant population. Epidemiology deals with outbreaks and spread of diseases in a population.

Need of epidemiology and plant protection forecasts :

– Epidemiological studies generate a lot of information on different aspects of disease development and developing technology for plant disease management.

– The technology based on epidemiological principles is logical as they are based on facts.

– Epidemiological studies helps in making tactical decisions about the need to implement disease management measure.

– Epidemiological studies helps in making strategic decisions about prediction of the risks involved in planting a certain crop and assessment of climate change effects and adaptation.

Elements of an epidemic :

The three elements of an epidemic are:

– Susceptible host
– Virulent pathogen
– Favourable environment.

Factors that affect the development of epidemics:

Levels of genetic resistance or susceptibility of the host :

Host plants carrying race-specific (vertical) resistance do not allow a pathogen to become established in them, and thus no epidemic can develop. Host plants carrying partial (horizontal) resistance will probably become infected, but the rate at which the disease and the epidemic will develop depends on the level of resistance and the environmental conditions.

Degree of genetic uniformity of host in a particular field:

When genetically uniform host plants, particularly with regard to the genes associated with disease resistance, are grown over large areas, a greater likelihood exists that a new pathogen race will appear that can attack their genome and result in an epidemic. This phenomenon has been observed repeatedly, for example, in the *Cochliobolus (Helminthosporium)* blight on Victoria oats and in southern corn leaf blight on corn carrying Texas male-sterile cytoplasm.

Type of crops :

Diseases of annual crops, such as corn, vegetables, rice, and cotton and in foliar, blossom, or fruit diseases of trees and vines, epidemics generally develop much more rapidly (usually in a few weeks) than they do in diseases of branches and stems of perennial woody crops such as fruit and forest trees. Some epidemics of fruit and forest trees, e.g., *Tristeza* in citrus, pear decline, Dutch elm disease, and chestnut blight, take years to develop.

Age of host plants:

Plants change in their reaction (susceptibility or resistance) to disease with age. The change of resistance with age is known as ontogenic resistance. In some plant–pathogen combinations, e.g., *Pythium* damping off and root rots, downy mildews, peach leaf curl, systemic smuts, rusts, bacterial blights and viral infections, the hosts (or their parts) are susceptible only during the growth period and become resistant during the adult period.

Pathogen factors that affect development of epidemics:

Levels of virulence :

Virulent pathogens capable of infecting the host rapidly ensure a faster production of larger amounts of inoculum, and, thereby, disease, than pathogens of lesser virulence.

Quantity of inoculum near hosts:

The greater the number of pathogen propagules (bacteria, fungal spores and sclerotia, nematode eggs, virusinfected plants, etc.) with in or near fields of host plants, the more inoculum reaches the hosts and at an earlier time, thereby increasing the chances of an epidemic greatly.

Type of reproduction of the pathogen :

Monocyclic diseases:

Diseases which completes only one generation of the pathogen in the life of a crop. E.g. smuts, short cycle rusts.

Polycyclic diseases:

There are several generations of the pathogen in the life of a crop. E.g. leaf rust, leaf blight, leaf spots, powdery mildews.

Polyetic diseases :

Pathogens that require more than a year to complete a reproductive cycle. Examples are cedar-apple rust (2 years), white pine blister rust (3–6 years) and dwarf mistletoe (5–6 years).

Ecology of the pathogen :

Some pathogens, such as most fungi and all parasitic higher plants, produce their inoculum (spores and seeds, respectively) on the surface of the aerial parts of the host. Other pathogens, such as vascular fungi and bacteria, mollicutes, viruses and protozoa, reproduce inside the plant.

Environmental factors that affect development of epidemics :

Moisture :

Abundant, prolonged, or repeated high moisture, whether in the form of rain, dew, or high humidity, is the dominant factor in the development of most epidemics of diseases. Moisture not only promotes new succulent and susceptible growth in the host, but, more importantly, it increases sporulation of fungi and multiplication of bacteria.

Temperature :

Epidemics are sometimes favored by temperatures higher or lower than the optimum for the plant because they reduce the plant's level of partial resistance. At certain levels, temperatures may even reduce or eliminate the race-specific resistance of host plants. The most common effect of temperature on epidemics, however, is its effect on the pathogen during the different stages of pathogenesis, *i.e.*, spore germination or egg hatching, host penetration, pathogen growth or reproduction, invasion of the host, and sporulation.

Effect of human cultural practices and control measures:

Site selection and preparation:

Low-lying and poorly drained and aerated fields, especially if near other infected fields, tend to favour the appearance and development of epidemics.

Selection of propagative material:

The use of seed, nursery stock and other propagative material that carries various pathogens increases the amount of initial inoculum within the crop and favours the development of epidemics greatly. The use of pathogen-free or treated propagative material can reduce the chance of epidemics greatly.

Cultural practices :

Continuous monoculture, large acreages planted to the same variety of crop, high levels of nitrogen fertilization, no-till culture, dense plantings, overhead irrigation, injury by herbicide application and poor sanitation all increase the possibility and severity of epidemics.

Disease control measures :

Chemical sprays, cultural practices (such as sanitation and crop rotation), biological controls (such as using resistant varieties) and other control measures reduce or eliminate the possibility of an epidemic. Sometimes, however, certain controls, e.g., the use of a certain chemical or planting of a certain variety, may lead to selection of virulent strains of the pathogen that either are resistant to the chemical or can overcome the resistance of the variety and thus, lead to epidemics.

Introduction of new pathogens :

The ease and frequency of worldwide travel have also increased the movement of seeds, tubers, nursery stock, and other agricultural goods. These events increase the possibility of introducing pathogens into areas where the hosts have not had a chance to evolve resistance to these pathogens. Such pathogens frequently lead to severe epidemics. Examples are chestnut blight, Dutch elm disease, and citrus canker caused by the bacterium *Xanthomonas campestris* pv. *citri.*

Why modelling:

– To know about behaviour of a disease in a population.

– To understand the relation between different

Table 1: Plant disease epidemic in India

Sr. No.	Disease	Year	Location
1.	Wheat rust	1905	Punjab
2.	Karnal bunt of wheat	1978,1981-83, 1986	North India
3.	Rice blast	1919	Tanjor delta of Tamil Nadu
4.	Brown spot of rice	1942-43	West Bengal
5.	Ergot of bajra	1956	Maharashtra
6.	Red rot of sugarcane	1939-40	U.P. and Bihar
7.	Bacterial blight of rice	1959, 1962	Maharashtra and Bihar
8.	Tungro of rice	1998	North India
9.	Apple scab	1973	Kashmir Valley
10.	Apple scab	1983	Himachal Pradesh

elements of epidemics.

– Identify the critical factors driving epidemics.

– Prediction of disease behaviour.

– Predict the effect of disease control strategies.

Basis of modelling :

All the epidemiological models are based on the cyclic pattern of disease occurrence. *i.e.*

– Monocyclic disease Fig. 1.

– Polycyclic disease Fig. 2.

How to reduce disease incidence, x, at any point in the epidemic:

Reduce initial inoculum, Xo

Reduce rate constant, R

Reduce duration of epidemic, t.

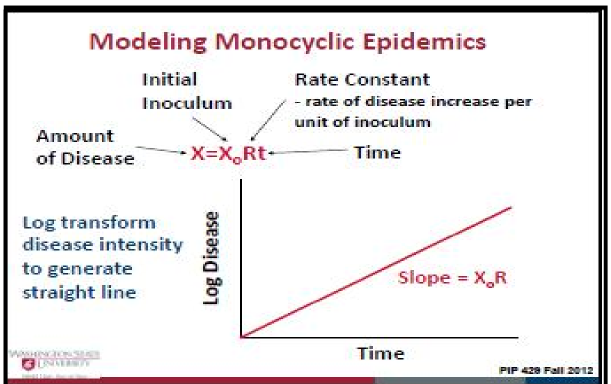

Fig. 1 : Modeling of monocyclic diseases

How to reduce disease incidence, X, at any point in the epidemic:

Reduce initial inoculum, Xo

Reduce rate of infection, r

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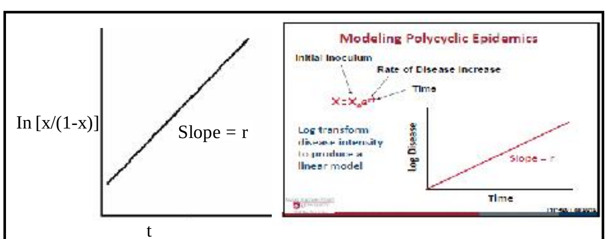


Fig. 2 : Modeling of polycyclic diseases

Managing epidemics:

Monocyclic Model $X = X_oRt$

Polycyclic Model: $X = X_oe^{rt}$.

Two ways to reduce X (disease):

Reduce the initial inoculum X_0

– Delay onset and reduce the duration of the epidemic.

Reduce the rate of disease development (r**).**

Effect of X_0 on epidemic development:

X_0 depends upon:

– Inoculum from previous crops within a field.

– Inoculum from crops in adjacent fields.

X_0 is affected by:

– By destroying infected plant debris.

– By removing diseased plants.

– Through chemical seed treatments.

– Use of protective fungicides.

– Race-specific disease resistance.

– Biological control agents targeted at initial inoculum.

Effect of r on epidemic development:

r depends upon:

– Reproductive potential of the pathogen.

– Virulence of the pathogen.

– Susceptibility of the host.

– Conduciveness of environment.

r is affected by:

– Non-specific disease resistance.

– Use of systemic fungicides.

– Cultural practices that alter environment.

– By removal of diseased plants.

Mathematical modeling in plant disease epidemiology :

Disease progress curves :

Disease progress curves show the epidemic dynamics over time (Agrios, 2005). This mathematical tool can be used to obtain information about the appearance and amount of inoculum, changes in host susceptibility during growing period, weather events and the effectiveness of cultural and control measures. 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 epidemics (Xu, 2006). The growth models commonly used are: Monomolecular, Exponential, Logistic and

Gompertz (Zadoks and Schein, 1979; Nutter, 1997; Nutter and Parker, 1997; Xu, 2006).

Why use disease progress curves:

– To compare control measures.

– To compare effect of environment on disease development.

– Prediction of future disease development.

– Disease forecasting for improved control.

– To predict severity over host growth stages.

Most commonly used growth models are Monomolecular, exponential, logistic and gompertz (Zadoks and Schein, 1979; Nutter, 1997; Nutter and Parker, 1997 and Xu, 2006).

Monomolecular:

This growth model is appropriate for modeling epidemics where there is not secondary spread within a growing season, meaning that the plant disease has a single cycle during growing season (Nutter, 2007). This model is also called negative exponential model (Campbell and Madden, 1990).

Exponential:

This model is also known as the logarithmic, geometric or Malthusian model. This growth model is appropriate when newly diseased (infected) individuals lead to more diseased (infected) individuals and has been used to model changes in disease prevalence on a geographic scale, it can be applied to describe the very early stages of most polycyclic epidemics (Nutter, 2007).

Logistic:

It was proposed firstly by Veshulst in 1838 to represent human population growth. A second type of logistic model was proposed by Van der Plank (1963), being more appropriate for most polycyclic diseases, meaning that there is a secondary spread within a growing season (Nutter, 2007). This growth model is the most widely used for describing epidemics of plant disease (Segarra *et al.*, 2001 and Jeger, 2004).

Gompertz:

This growth model is appropriate for polycyclic diseases as an alternative to logistic models. Gompertz model has an absolute rate curve that reaches a maximum more quickly and declines more gradually than the logistic models (Nutter, 2007).

Fig. 3 shows examples of disease progress curves represented by growth models, where it can be seen that Gompertz and logistic models have a characteristic sigmoid form and an inflection point meaning secondary inoculation or plant-to-plant spread within the crop in contrast to monomolecular model, which does not have inflection point. The exponential model presents a very small value at the beginning comparing with the other models and latter it increases exponentially.

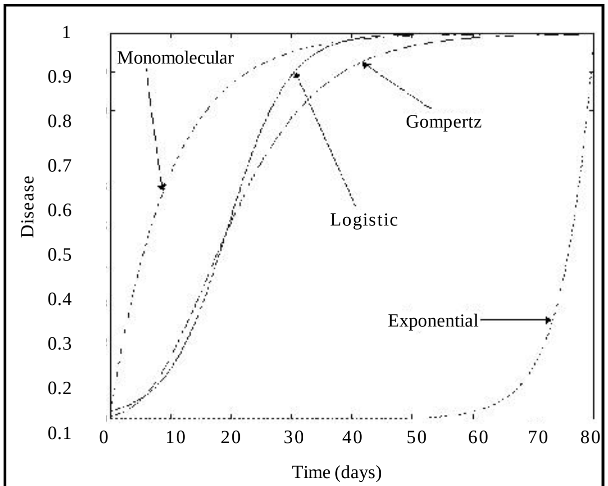


Fig. 3 : Examples of disease progress curves represented by monomolecular, exponential, logistic and gompertz models

In general, growth models that incorporate few variables to describe temporal disease dynamics have a good performance; however, this kind of models sometimes do not satisfy the acquiring process of key characteristics because they frequently ignore relevant variables that affect the epidemic development (Xu, 2006), e. g. host growth, fluctuating environmental condition, length of latent and infectious period, etc.

Linked differential equations (LDE):

This mathematical tool achieves the description of plant disease epidemics by modeling each of the variables considered to be determinant in epidemic development and latter making the link between them. LDE allows the inclusion of new terms into the model as needed (Madden, 2006). When this technique cannot be easily integrated to obtain an analytical solution, it needs numerical methods to provide a numerical solution (Xu, 2006 and Madden, 2006); now-a-days, the advances in computational technology have permitted that numerical solutions could be easily obtained through mathematically-oriented software like MATHCAD or MATHEMATICA (Madden, 2006). Usually LDE is employed to investigate relationships of the plant disease dynamics in relation to the host, environment and human intervention (Van Maanen and Xu, 2003).

Area under disease progress curve (AUDPC):

This technique is very useful when the observed patterns cannot be fitted by progress disease curves (Van Maanen and Xu, 2003 and Xu, 2006). AUDPC is the amount of disease integrated between two times of interest and it is calculated regardless the curve shape (Shaner and Finney, 1977). Disease progress data is summarized into one value by AUDPC; it is suited when host damage and the amount and duration of the disease are proportional (Xu, 2006). If a model fits satisfactorily the disease patterns, AUD PC can be obtained from the model by integrating over certain interval of time (Jeger and Viljanen-Robinson, 2001).

$$\text{AUDPC} = \sum\left[\left(\frac{\text{Yi}+\text{Yi}+1}{2}\right)\right] \text{x}\,(\text{ti}+1-\text{ti})$$

where,

Yi = Disease severity/incidence at time ti

Yi+1= Disease severity at time ti+1

ti = Time when disease severity/incidence was Yi

$$\text{ti}+1 = \frac{\text{Time when disease severity}}{\text{Incidence was Yi}+1}$$

Computer simulation of epidmeology:

The availability of computers has allowed plant pathologists to write programmes that allow the simulation of epidemics of the most important plant diseases. One of the first computer simulation programmes, called EPIDEM, was written in 1969 and resulted from modelling each stage of the life cycle of a pathogen as a function of the environment. EPIDEM was designed to simulate epidemics of early blight of tomato and potato caused by the fungus *Alternaria solani*. Subsequently, computer simulators were written for Cercospora blight of celery (CERCOS), for *Mycosphaerella* blight of chrysanthemums (MYCOS), for southern corn leaf blight caused by *Cochliobolus (Helminthosporium) maydis* (EPICORN), and for apple scab caused by *Venturia inaequalis* (EPIVEN). A more general and more flexible plant disease simulator, called EPIDEMIC, was written primarily for the stripe rust of wheat but could be modified easily for other host–pathogen systems. Computer simulation programs are now available for numerous plant diseases (Table 2).

New tools in plant disease epidemiology:

Remote sensing :

Remote sensing usually refers to the use of instruments for measuring electromagnetic radiation reflected or emitted from an object. The instruments record reflected or emitted radiation in the ultraviolet, visible, or infrared part of the spectrum. The instruments used for remote sensing may be hand-held, ground-based cameras with films and filters, digital cameras, video systems, and radiometers or they may be carried on balloons, aircraft and satellites. The various remote sensing instruments store data obtained from field situations, and data are then printed out and are analysed directly or by transferring them to a computer and creating visual images of data:

Objectives of remote sensing in plant pathology:

– Assessment of disease over a vast area.

– To know the relationship of diseases and environment.

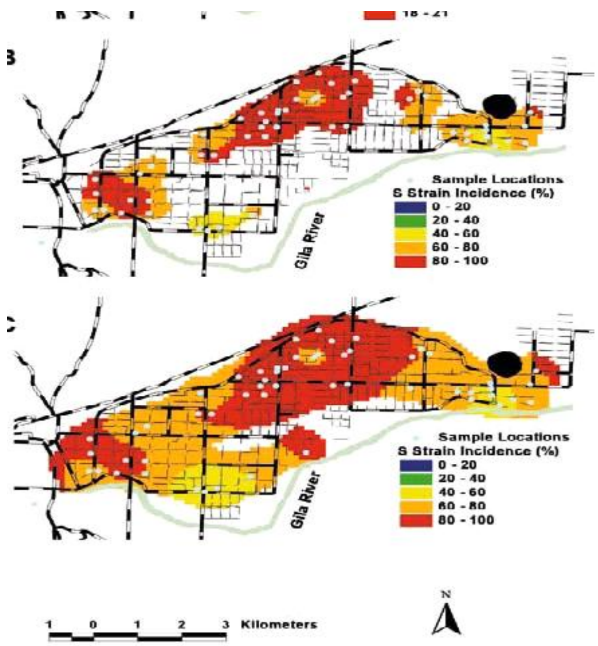
– To know the origin and development of epidemics.

Table 2: Computer based models

Models	Disease	Pathogen
MYCOS	Blight of chrysanthemum	*Mycosphaerella* spp.
EPIMAY	Southern leaf blight of maize	*Helminthosporium maydis*
EPIDEMIC	Stripe rust	*Puccinia striformis*
EEPIVEN	Apple scab	*Venturia inequalis*
PLASMO	Downy mildew of grapes	*Plasmopara viticola*
EPIDEM	Early blight of potato	*Alternaria solani*
BLIGHTCAST	Late blight of potato	*Phytophthora infestans*

Aerial photography:

It detects object on land over a larger area. It refers to to photography and electronic image analysis, usually of large areas of fields or of mountains. The images or photographs are taken through aerial photography, ground-based sensor data, and satellite-borne and airborne sensors. Panchromatic colour and especially infrared aerial photography could be used to detect rusts and viral diseases of small grains and certain diseases of citrus. Later, infrared photography was used in England for late blight of potato.



Satellite imaging:

This can be effectively monitored by weather satellites. Sequential pictures show the movement of these systems before they arrive in an area. By monitoring epidemic favouring systems using a satellite, the disease occurrence on the field can be monitored. The spread and deposition of stem rust pathogen of wheat is influenced by definite synoptic weather conditions called Indian stem rust rules. Earth resources technology satellites (LANDSAT, 1972, USA) LANDSAT covers the entire globe every 18 days scanning the same area at a fixed time.

Global positioning system:

The global positioning system (GPS) consists of a handheld device that is coordinated with a global system of man-made satellites and, depending on the accuracy and coordination, provides quite accurate readings of the coordinates of the position of the device. GPS enables one to pinpoint an individual tree or a specific area or areas of the field that are affected by a pathogen, which then can be visited and examined again periodically for incremental advance of the symptoms. Similarly, the selected trees or areas could be treated with the appropriate pesticide or other treatment wherever the pathogen is present without the need to treat the entire field. GPS can also be used to apply pesticides, plant nutrients, and so on in only the areas of the field that are infested with the pathogen or in areas deficient in a particular micro- or macronutrient. Elimination of the pathogen from the field by early detection and treatment is often effective in not allowing the pathogen to cause an epidemic in the field and beyond.

Expert system in plant disease management:

Expert system is used for diagnosis of plant disease. It utilize a bank of data pertinent to the problem stored in the computer and knowledge input by the expert followed by conclusion or action and finally recommendation. Expert system is also reviewed and if necessary, revised by other experts. The first expert system in plant pathology was developed in 1983 to diagnose nearly 20 soybean diseases in USA (Table 3).

Table 3 : Expert system for management of plant disease

Expert system	Importance
Plant/ds	For diagnosis of 20 soyabean diseases in USA
Pomme	Manage diseases of apple
Potatoes	Expert system for late blight of potato
Tommex	It used 78 questions, 87 photographs for diagnosis of 37 diseases of tomato
Grenman	Green house disease management
Consellor	For the disease management of wheat
Calex	For peach and nectarines

How plant diseases can be managed through epidemiological models:

BLITECAST:

BLITECAST was developed in USA for late blight of potato (*Phytophthora infestans*). According to this model the initial appearance of late blight is forecasted 7 to 14 days after the occurrence of 10 blight favourable days. Blight favorable conditions are 5 day average temperature is 25.5°C and the total rainfall for the last 10 days is more than 3.0 cm. A computerized version (BLITECAST) has also been developed in the U.S.A for forecasting potato late blight (Table 4).

Table 4: Late blight of potato

Sr. No.	Author	Country	Environmental parameters conducive to blight development
1.	Van Everdingen	Netherlands	Dutch rules based on four factors Dew point Minimum temperature >10°C Cloudiness Rainfall for at least 4hrs during night
2.	Wallin	USA	Based on hourly RH and temperature Maximum temperature 21.1°C Minimum RH 95% for at least 10 hrs Duration depends on temperature between 7.2 and 26.7 °C, of minimum relative humidity of 90%
3.	Bhattacharya *et al.*, 1983	India	First forecast based on rainfall and mean temperature and the second one based on temperature and relative humidity

How farmers utilize BLITECAST:

When a farmer desires BLIGHTCAST he telephones the BLIGHTCAST operator and reports the most recently recorded environmental data. The operator calls for the blight cast programmes in the computer *viz.*, typewriter terminal and feeds the new data into the computer.Within a fraction of second the computer analyses the data and series of a forecast and spray recommendations to the operator who relays it to the farmer. The entire operation can be completed during standard three minutes telephone call. The system makes one of the four recommendations *viz.*, no spray, late blight warning, 7 days spray schedule or 5 days spray schedule. The last 5 days spray schedule is issued only during severe blight weather (Table 5).

Table 5 : Late blight forecasting models

Sr. No.	Model	Given by
1.	BLIGHTCAST	Krause *et al.*, 1975
2.	JHULSACAST	Singh *et al.*, 2000
3.	SIMCAST	Grunwald *et al.*, 2002
4.	NEGFRY	Runno and Kopple, 2002
5.	WEB BASED DSS	Thind *et al.*,2013

INDO-BLIGHTCAST:

INDO-BLIGHTCAST- is a web based forecasting model developed to predict the first appearance of late blight disease using daily weather data of meteorological stations. This is an improvement over the JHULSA CAST model, which requires hourly data of temperature, relative humidity and daily rainfall. The intensive data requirement as well as location specific calibration of JHULSACAST was a serious impediment to its wide spread use. The INDO-BLIGHTCAST, however, is applicable pan India, since, it is web based, it requires only daily weather and does not need local calibration for different regions. Hence, it is more robust and its predictions are more broad based. INDO-BLIGHT CAST has two modules one for data entry and the other for the general users to see the status of late blight forecast.

Development of a web-based decision support system for late blight of potato :

A dynamic risk evaluation model based on duration of relative humidity of more than 90 per cent at a range of temperatures was used for forecasting potato late blight. For this six automatic weather stations (AWSs) were installed in different potato growing districts of Punjab. Weather data from these AWSs were transmitted through data transfer sim cards to a receiver and transferred to a computer where it was stored for final analysis using the risk evaluation model. This model was validated under field conditions by determining disease severity values for the cropping seasons 2009-10 and 2010-11. Based on this model, a web-based decision support system (DSS) was developed. The website (*http:dss-lb.pau.edu*) was designed to provide information on weather data of different potato growing districts and expected disease severity values. It also gave information about favorable conditions for disease development, Accordingly, the farmers were issued advisories whether or not to initiate fungicide applications to manage late blight. The DSS has proved useful in economizing on fungicide applications.

APPLE SCAB

W D Mills determine the temperature and leaf wetting requirement for light, Moderate and heavy infection by ascospores and conidia in orchard condition for apple scab, and developed the Mill's table.

Interpretation of Mill's table found that leaf wetness for:

– Time period for 9 hours leads to ascospore infection.

– Time period for 5.9 hours leads to conidial infection.

– Time period of 9 days leads to symptoms expressions of the disease at optimum temperature range of 18.2 to 23.8°C.

Apple scab forecasting models:

The first scab simulation models were EPIVEN by Kranz *et al.* (1973), VISIM by Seem and Sutton. Weather parameters and the amount of inoculum were included in order to forecast disease infection and threshold levels. In the later published models, all major components of the apple scab control were incorporated, including fungicide residue, fungicide efficacy, fungicide activity (protectant, curative and eradicant activity) pathogen resistance to fungicides, amount of inoculum and economics.

Mashobra disease forecast:

Success story of scab management in Himachal Pradesh (Table 6):

Based on the information validated on the overwintering in the development processes of scab fungus, RHRS developed the computer based Mashobra disease forecast programme to predict the annual epidemic conditions with an input of integrated management options. After this the farmers are recommended to use the fungicides based on primary and secondary disease cycles for the cure of existing infection and eradication of the pathogen with minimum sprays in a season. RHRS has also created awareness among the apple growers about the climatic conditions that help in the spread of apple scab fungus. The farmers (those who have scab infection during the last three years) were asked to develop data for temperature and rainfall of their orchards from the leaf fall date to the maturation of the overwintering inoculum on the orchard floor. For collecting data, farmers are provided with low cost weather monitoring device *i.e.* simple minimum and maximum thermometer and self-made three layered

Table 6: Criteria for primary and secondary scab infection based on mills infection table for H.P.

Avg. daily temp. (°C)	Minimum wetting hours of leaves for infection to start with		Days required (After infection for symptom appearance)
	Ascospore	Conidia	
17.2-23.8	9	5.9	9
16.6-16.1	9	5.9	10
15.5	9	6.3	11
15.0-14.4	10	6.6	12
13.8-13.3	10	7.0	13
12.7-12.2	11	7.5	14
11.6-11.1	12	7.9	15
10.5	13	8.7	16
9.4-9.8	15	9.8	17
8.2	17	11.3	17
7.7	19	12.6	No infection

Thakur *et al.*, 2005

newspaper pad (which can hold rain moisture for 1-10 hours after rain) to measure the comparable moisture holding by the apple leaves. This microclimatic input of the orchard of the farmers is in use at specified intervals to predict the scab infection conditions of their orchards. This infection criteria of an individual orchard if coincides with the standardized method, the farmers of the sampled area are advised for the outbreak of scab. The hi-tech programme invented by RHRS is a breakthrough in controlling this major horticulture disease. Preventive measures has been taken and thus, in Himachal Pradesh the disease is observed now-a-days but not to the status of economic damage to either on leaves or fruits. The technique has guided the farmers and achieved upto 40 per cent reduction in fungicides use over the years.

Epidemilogical model for wheat rust:

Forecasting wheat stem rust epidemic is done by analysing the rain samples which give precise data for inoculum present in the air. Moreover, several wind trajectors are also prepared to survey the air-borne primary inoculums and its deposition. It has been observed that primary inoculum comes from South India, to the plains of Central and North India.

Rust development of epidemics:

Rust development of epidemics (RustDEp) is a dynamic simulator of the daily progress of brown rust severity on wheat (Rossi *et al*., 1997).

It takes into account:

– The proportion of spores able to establish new infections influenced by temperature and leaf wetness.

– Latent period depends on temperature.

– Infection period depends on temperature and host growth stage.

In the RustDEp model, the inputs of meteorological data are recorded by a weather station, allowing more accurate simulation of the disease progress.

Predicting rust epidemic in India:

Nagarajan and Singh formulated " Indian Stem Rust Rules" for *Puccinia graminis tritici*. These rules explain satisfactorily if the primary inoculum from South India would travel tens of hundreds of km before its deposition in central India or not.

Indian stem rust rules:

The stem rust prediction methods consists of following steps:

– Check if there were any rains during November in central India coupled with southerly winds.

– Check the urediniospore content of the rain.

– If a tropical cyclone occurred during November, the disease would appear near the area where the cyclone dissipated. If the inoculum arrives early, the disease can develop into severe proportions. If rainfall satisfying the weather condition of rule 2 or 3 occurred during January or February, only traces of the disease would appear, that is too late in the crop season to be of serious threat.

– Check the weather over the area of urediniospore deposition.

– Check the viability of the transported spores.

– Check if the ground level conditions are favorable for infection or not.

– If all the conditions are satisfied, the first detectable infection could occur in 25 to 30 days at locations close to where the cyclones dissipated.

Conclusion:

Mathematical tools have been employed to create models which give a description of epidemic dynamics. Modelling and computer simulation provides continuous information not only on the spread and severity of the disease over time but also final crop and economic losses likely to be caused. Epidemiological models through forecasting helps farmers to determine whether a plant infection is likely to occur so that they can decide whether to spray a crop right away or wait for more days before spray. If disease forecasting allow them to wait, they can reduce expenditure on chemicals etc. on labor and will saves money substantially.

REFERENCES

Agrios, G.N. (2005). *Plant pathology.* 5th Ed., Elsevier Academic Press, London, United Kingdom.

Bhattacharyya, S.K., Phadatare, S.G., Khanna, R.N., Srivastava, D.S. and Prasad, B. (1983). Efficacy of some fungicides in controlling late blight of potato in India. *Indian J. Agric. Sci.*, **53**: 153-157.

Campbell, C.L. and Madden, L.V. (1990). *Introduction to plant disease epidemiology.* John Wiley & Sons, New York, NY, USA.

Grunwald, N.J., Cadena Hinojosa, M.A., Rubio Covarrubias,

O.A., Rivera Peña, A., Niederhauser, J.A. and Fry, W.E. (2002). Potato cultivars from the Mexican national program: sources and durability of resistance against late blight. *Phytopathology,* **92** : 688-693.

Jeger, M.J. and Viljanen-Rollinson, S.L.H. (2001). The use of the area under disease-progress curve (AUDPC) to assess quantitative disease resistance in crop cultivars. *Theor. Appl. Genet.,* **102**: 32-40.

Jeger, M.J. (2004). Analysis of disease progress as a basis for evaluating disease management practices. *Annual Rev. Phytopathol.,* **42**: 61-82.

Kranz, J., Mogk, M. and Stumpf, A. (1973). EPIVEN: ein Simulator fur Apfelschorf. *Z Pflanzenkr,* **80**: 181-187.

Krause, R.A., Messie, L.B. and Hyre, R.A. (1975). BLIGHTCAST: Computerized forecast of potato late blight. *Plant Disease Reporter,* **59**: 95.

Madden, L.V. (2006). Botanical epidemiology: Some key advances and its continuing role in disease management. *European J. Plant Pathol.,* **115**: 3-23.

Nutter, F.W. Jr (1997). Quantifying the temporal dynamics of plant virus epidemics: A review. *Crop Prot.,***16**: 603–618. doi: 10.1016/S0261-2194 (97) 00055-0.

Nutter, F.W. Jr. and Parker, S.K. (1997). Fitting disease progress curves EPIMODEL. In: *Exercises in plant disease epidemiology.* Francl, LJ and Neher DA (eds). APS Press, St. Paul, MN, USA, pp. 24-28.

Nutter, F.W. Jr. (2007). The role of plant disease epidemiology in developing successful integrated disease management programmes. pp. 45-79. In: *General concepts in integrated pest and disease management*. A. Ciancio and K.G. Mukerji, Ed. Springer-Verlag, Dordrecht, The Netherlands.

Rossi, V., Racca, P., Giosue, S., Pancaldi, D. and Alberti, I. (1997). Simulation model for the development of brown rust epidemics in winter wheat. *European J. Plant Pathol.,* **103**: 453–465.

Runno, E. and Koppel, M. (2002). Use of potato late blight control system Negfry in Estonian conditions. Research for rural development 2002. International Scientific Conference Proceedings, Jelgava.pp. 61-64.

Segarra, J., Jeger, M. and Van den Bosch, F. (2001). Epidemic patterns and dynamics of plant disease. *Phytopathology,* **91**: 1001–1010.

Singh, B.P., Islam Ahmed, Sharma, V.C. and Shekhawat, G.S. (2000). JHULSACAST: A computerized forecast of potato late blight in Western Uttar Pradesh. *J. Indian Potato Assoc.,* **27**: 25-34.

Thakur, V.S., Verma, N. and Verma, S. (2005). Effect of meteorological factors on the development of lesion density in apple scab epidemic in Himachal Pradesh. *Hort. J.,* **18**(1): 4-9.

Thind, T.S., Bala, Anju, Mukerjee, J., Jolly, R.K., Kumar, Pradeep, Singh, Amarjeet and Sekhon, P.S.(2013). Development of a web-based decision support system for late blight of potato. *Plant Disease Res.,***28** (1): 66-70.

Van der Plank, J. E. (1963). *Plant diseases*. Epidemics and Control. Academic Press, New York, U.S.A.

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

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

Zadoks, J. C. and Schein, R. D. (1979). *Epidemiology and plant disease management.* Oxford University Press, New York, U.S.A.