Mini Review

Plant Disease Epidemiology: Disease Triangle and Forecasting Mechanisms In Highlights

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Abstract | Concerns are increasing every day as crops are continuously under threat by various plant diseases worldwide. A sudden epidemic breakout of any plant disease can cause huge economic losses leading towards the famine. To cope with this situation, understanding plant disease triangle and disease epidemic forecasting is very important. So here we have briefly introduced plant disease epidemiology through highlighting its various types by giving important examples. We further have explained the plant disease triangle and disease forecasting systems via inclusion of various models being utilized worldwide.

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Introduction

Studying plant diseases in a particular plant population is known as plant disease epidemiology (PDE) (Nutter, 2007). Plant diseases are caused by the vast circle of diversified pathogens which continuously tend to undergo mutations and recombination, thus generating their new strains efficiently for their survival in the ecosystem (Ventura et al., 2007; Cangi et al., 2016). The pathogen survival strategies mostly lead towards the severe epidemic breakout of plant diseases leading towards the huge economic losses (Jones, 2014; Islam et al., 2017a). PDE involves the striving efforts of the researchers to intervene the favorable conditions of plant disease development thus considerably lowering the economic losses (Jones, 2014). Firstly in 1963, J.E van der Plank introduced about the tools that could have been possibly used for predicting epidemic break down of some diseases caused by foliar pathogens (Drenth, 2004). Visually, PDE involves integrated strategy via incorporation of agronomical, biological, ecological and statistical tools (Madden et al., 2007; Jones 2014). Explaining these tools, biological studies are necessary for better understanding of pathogen reproductive cycle and its developmental stages. Similarly, disease incidence is calculated via incorporation of agronomic values (Ward, 2013). While plant species, pathogen races, environmental fluctuations, insect vectors are broadly a part of ecological studies. All the above mentioned practices are calculated via statistical tools to better understand PDE (Madden et al., 2007; Arneson, 2011). Some historical PDE examples include Dutch elm disease of oak plants, *Phytophthora infestans* caused late blight of potato resulting in great Irish famine (Cormac, 2006). PDE can be extremely helpful in adopting the better management strategies against plant diseases. So here we have highlighted various

elements of epidemics through disease triangle, types and disease forecasting systems via incorporation of various examples.

Types of PDE

Various types of PDE can be stated depending upon the virulence of pathogen strains and cultivation plans. These may include monocyclic, polycyclic, bimodal polycyclic and polyetic PDEs (Madden et al., 2007; Arneson, 2011). Slowly reproducing pathogens having one infection cycle in a single year can result in Monocyclic PDE. For example, *Fusarium wilt* of flex caused by soil born *Fusarium oxysporum f.sp. lini.* On the contrary, the pathogens embedding the multiple infection cycles in a single season lead towards the Polycyclic PDE. e.g. airborne popular fungal disease powdery mildew. Similarly, bi-modal polycyclic PDE is categorized with multiple infections of single plant at different time. For example, stone fruits and blossoms are infected by brown rot diseases of stone fruits and blossoms (Arneson, 2011). Sometimes for determining the type of PDE, it is important to overlook the pattern of crops being grown at that particular place for several years. For example, if a single crop is being grown every year in that vicinity again and again, this leads towards the accumulation of the pathogen strains and building up of the inoculums for a particular disease. This type of PDE is referred as polyetic PDE and may be caused via both monocyclic and polycyclic pathogens (Madden et al., 2007). For example, powdery mildew of apple epidemics caused by polycyclic pathogen i.e. *Podosphaera leucotricha* and Dutch elm disease epidemics prevailed due to monocyclic *Ophiostoma novoulmi*.

The disease triangle

The disease triangle embeds three common elements i.e. host, pathogen, environment (Islam et al., 2017a). Exclusively for PDE, the triangle completes when the host is susceptible, pathogen is virulent and environment is favorable for infection establishment (Agrios, 2005). In simple words, the conjugation of above three guarantee the disease development. The other important thing that can play its role in all this process is time. So to rule out the chances of disease, any of the three factors can be modified or fluctuated. For example, plants susceptibility can be minimized via incorporation of disease resistant or tolerant plant cultivars (Noman et al., 2016, 2017; Islam et al., 2017 b,c). Pathogen can be managed via application of chemicals, cultural methods or other practices (Rehman et al., 2013; Islam et al, 2016a,b; Islam et al., 2017d). The environmental conditions are natural and cannot be manipulated via physical efforts by human beings (Tilman and Lehman, 2001; Martin et al., 2016). But the forth factor i.e. time allows us to quickly manage the pathogen before occurrence of favorable pathogenic environmental conditions. The time is very crucial as it is variable for every pathogen regarding infection establishment (Agrios, 2005). Other minor elements for PDE may involve role of various species which have variable period of resistance against pathogenic strains as their resistance level can increase with the maturity thus leading towards the development of ontogenic resistance (Drenth, 2004; Agrios, 2005). If the pathogen is transmitted via vectors then the population of vectors in that particular area is also one of the curial elements that are required for PDE. For example, begomovirus diseases as these viruses as transferred through whitefly (Islam, 2017; Islam and Wu, 2017). As we reviewed that all the elements must occur simultaneously to generate the positive correlation for the establishment of disease. If the criteria is not fulfilled the PDE cannot result (Jones, 2014). For example, a corn field which may have previous residues on field having the fungal spores i.e. *Cercospora zeamaydis* which generates the grey lead spot disease of corn, but as we know the fungal spores require humid and wet conditions for their germination and infection initiation so if the environmental conditions are not in desired as mentioned, the spores will fail to germinate thus nullifying the disease chances (Nega et al., 2016). Similarly, if the environmental conditions are conducive and even the host is non resistant or weaker, but there is no pathogen strains, it's again a not disease prevailing conditions as it fails to complete the disease triangle (Scholthof, 2007) (Figure 1).

Plant disease forecasting

PDE is predicted via a management system through complete understanding of disease severity known as plant disease forecasting (PDF) (Esker et al., 2008). PDF is utilized by the state departments and farmers for making the economic decisions for the better management of plant diseases at field levels. The PDF involves various questions which are answered by the growers. These questions include information about susceptibility of cultivars, weather forecasts and existing disease symptoms. Intelligently answering these

Figure 1: *Various aspects of plant disease triangle. Where* **(A)** *No factor present,* **(B)** *Virulent pathogen is present but other two factors are absent,* **(C)** *Susceptible host exists but there is no pathogen and favoring environment,* **(D)** *Only favorable environment is prevailing but other two factors are lacking,* **(E)** *All three factors i.e. virulent pathogen, susceptible cultivar and conducive environment is existing at the same time. These conditions can lead towards PDE.*

questions by growers can help them in taking correct decisions through PDF systems (Arneson, 2011). PDF system relies upon plant-pathogen-environment interaction studies to predict the PDE. Here the most important factor that is uncertain and crucial is environment as the cultivars and pathogen existence stands stable. Environmental conditions directly affect the pathogen and cultivar performance as reviewed earlier with examples. A better PDF system embeds reliability, simplicity, cost effectiveness, and wide applicability to a number of diseases (Arneson, 2011). The PDF are normally designed for irregular and more damaging diseases rather than the regular diseases as growers well understood about the diseases that prevail every year and they can efficiently manage them using various methods. The first PDF was emerged to warn the farmers regarding Stewart's wilt and it was basically designed via indexing winter temperature with a theme that lower temperature will cause the death of vector thus leading towards the reduction in PDE (Drenth, 2004). But talking about the multiple PDF system, a successful example is EPIPRE (Epidemiology, prediction and prevention) system developed by Netherlands to forecast about PDE of winter wheat against multiple pathogens (Reinink, 1986) (Figure 2).

An online example is USPEST.org which forecasts about chances of plant disease occurrence on the basis of hourly leaf wetness period. For efficient PDF system, choice of model is very important. For example, simple PDF systems involve the simple linear regression models where x is the striker to give prediction about Y or population growth curve models can be employed depending upon the type and nature of epidemics (Cambel, 1990; Madden et al., 2007; Jones, 2014). However the polythenic PDE are predicted through utilization of logistic models, e.g. late blight

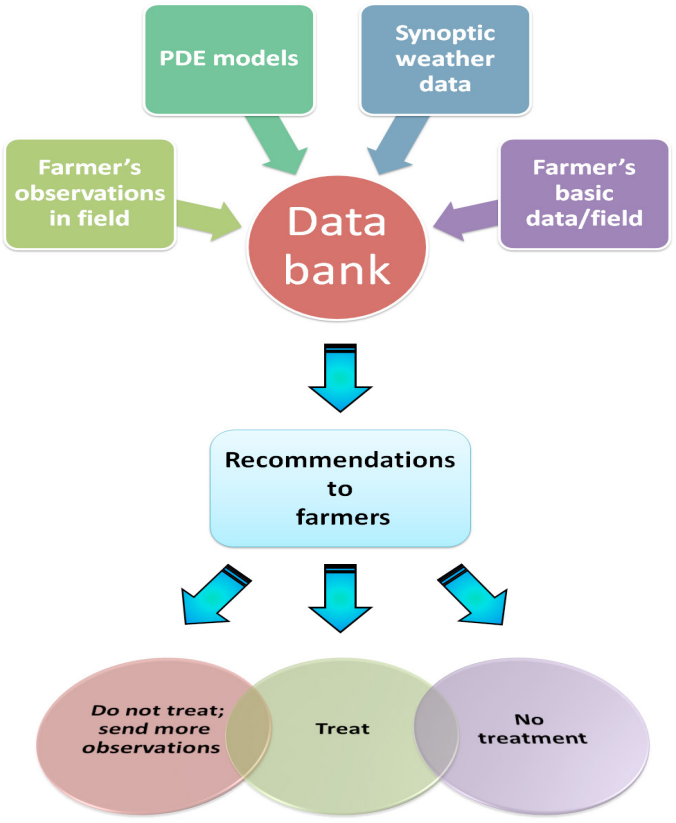

Figure 2: *EPIPRE model*

Table 1: *PDF systems*

#	Plant Diseases	Factors considered to develop PDF system	Countries using PDF system
1	Grapevine downy mildew	**1. Host Factors** a. Susceptible varieties b. Response at different growth stages c. Density and distribution in a given locality. **2. Pathogen factors** a. Amount of primary inoculum in the air, soil or planting material b. Dispersal of inoculum c. Spore germination d. Infection e. Incubation period f. Sporulation on the infected host g. Re-dispersal / Dissemination of spores h. Perennating stages i. Inoculum potential and density in the seed, soil and air **3. Environmental factors** a. Temperature b. Humidity c. Light intensity d. Wind velocity	Australia, France, Germany, Greece, Italy, Romania, Russian, Spain, Yugoslavia
2	Potato late blight		Australia, Brazil, Finland, France, Germany, Greece, Japan, the Netherlands, Norway, Peru, U.K, Russia
3	Apple and pear scab		Australia, Canada, U.S.A., Netherlands, New Zealand,
4	Tobacco blue mould		Canada, U.S.A.
5	Sugarbeet root rot (*Aphanomyces* sp.), Wheat brown (Leaf) rust, Corn bacterial wilt (*Erwinia stewartii*), Sugarbeet curly top		U.S.A.

of potato. But monomolecular model can be applied for monocyclic PDE. However, before application of any model for PDF, these should be tested again and again for their validation and efficiency through quantification of economic costs via overlooking false negatives and false positives (Madden et al., 2007). These two errors can completely deteriorate the effectiveness of any PDF system, so these errors should be carefully weighed before implementation of any model. Some examples of currently available PDF are mentioned in Table 1.

Conclusion and future prospects

Plant diseases are the continuous threat for the farmers as they can suddenly ruin them through their crop losses. Advance prediction of these diseases through PDF systems can be a very helpful solution in minimizing these losses. As the computer programming and literacy is spreading to each and every corner of the world, the development of computer based PDF systems is becoming easier. These systems can not only handle the larger data but also can generate prediction for large number of diseases via incorporation of huge information of pathogens. The online PDF systems can easily take the environmental forecast from various sources and can accurately predict the PDE. As the population is increasing day by day and to feed such huge population and food security PDE cannot be afforded, thus sincere and result based approached are need to exploited for timely prediction of plant diseases.

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