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AEROBIOLOGY IN NORTH-EAST INDIA IN THE CONTEXT OF EPIDEMIOLOGY AND FORECASTING FOR FUNGAL DISEASES OF MAJOR CROP PLANTS

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Key words : *Aerobiology, Epidemiology, Forecasting, Fungal diseases of crop plants, North-East India*

The role of aerobiology in plant pathology, plant disease, epidemiology and plant disease forecasting are provided. The review further focuses six decades of aerobiology in North-East India in the context of fungal diseases of cereals (rice, maize); pulses (broad bean, pea, common bean, black gram, soybean); vegetables (tomato, mustard, cabbage, potato); and cash crops (sugarcane, lemon). It also provides suggestions for plant disease management strategies.

INTRODUCTION

Researches on aerobiological approach to crop diseases are well established in many parts of India. But for the North-East India, it has been a virgin field (Irabanta Singh, 2006). The paper re-reviews the aerobiological works done in the North-East India during the last six decades. Further, short descriptions on the applications of aerobiology in plant pathology, plant diseases epidemiology and plant disease forecasting are also provided. Suggestions for plant disease management strategies are also elucidated at the end of the review.

AEROBIOLOGY IN PLANT PATHOLOGY

Most Plant Pathologists, interested in aerobiology, like to answer on the three questions, viz., (i) What can be expected? (ii) Where does it come from? and (iii) What will be impact? The three questions are closely related and equally important. Then what can be we do about it? With this question, however, they cross the borderline between both disciplines in the direction of pure plant pathology (Irabanta Singh, 2009).

The first three questions stated above are not new at all. The most important plant diseases were generally known as well as their life cycle, host range, geographical distributions and some of the relations between disease development and weather were largely understood. This knowledge was necessary for the next step, development of theories about the spread of plant diseases within the crops, from crop to crop, from one region to another. This has been called botanical epidemiology, a theme within the science of plant pathology with strong connections to aerobiology (Heestbeek and Zodoks, 1987). Many spores are killed during atmospheric dispersal as a consequence of exposure to atmospheric agents. However, a number of spores remain viable, some of which may be harmless while other scan cause diseases to plants. Therefore, monitoring of the air content of conidia or spores is important for a better understanding of the epidemiology of plant disease (Irabanta Singh, 2009).

At present, the interest of plant pathologists in the spread of plant pathogenic microorganisms is focused on three scale of observations, viz., (i) crop/field scale (epidemics), (ii) original continental scale (pandemics) and (iii) inter-continental scale (introduction). All the three scales are of aerobiological nature though those on the crop/field scale are only partially. The exception to this case should be the direct plant to plant contact by which disease can be transmitted (Frinking, 1993).

PLANT DISEASE EPIDEMIOLOGY

It is the study of disease in population (Agrios, 2005). Plant disease epidemiology is often looked at from a multidisciplinary approach, requiring biological, statistical, agronomic and ecological perspectives. Biology is necessary for understanding the pathogen and its life cycle. It is also necessary for understanding the physiology of the crop and how the pathogen is adversely affecting it. Agronomic practices often influence disease incidence for better or for worse. Ecological influences are numerous. Native species of plants may serve as reservoirs for pathogens that can cause disease in crops. Statistical models are often applied in order to summarize and describe the complexity of plant disease epidemiology so that disease process can be more readily understood (Areneson, 2001; Madden *et al.,* 2007). Based on J.E. Vander Plank's book "Plant Diseases, Epidemics and Control" (1963), we can model and determine threshholds for epidemics that take place in a homogeneous environment such as a mono-cultural crop field (Drenth, 2004).

Commonly the elements of an epidemic are referred to as the "disease triangle" – *susceptible host*, *pathogen* and *conducive environmen*t (Agrios, 2005). For example, maize (corn) is planted into a field with maize residue that has the fungus *Cercospora sorghi,* the causal agent of leaf spot of maize, but if the weather is too dry and there is no leaf wetness, the spores of the fungus in the residue cannot germinate and initiate infection. Likewise, if the host is susceptible and the environment favours the development of disease but the pathogen is not present, there is no disease. For example, the maize is planted into a ploughed field where there is no maize residue with the fungus *Cercospora sorghi* present but the weather supports long periods of leaf wetness, there is no infection initiated.

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There are two main types of epidemics, *viz.*, (i) monocyclic and (ii) polycyclic. Monocyclic epidemics are caused by pathogens with a low birth rate and death rate – meaning they only have one infection cycle per season. They are typical of soil borne diseases such as *Fusarium* wilt of flax. Whereas polycyclic epidemics are caused by pathogens capable of several infection cycles in a season. They are most often caused by airborne disease such as powdery mildew.

PLANT DISEASE FORECASTING

It is a management system used to predict the occurrence or change in severity of plant diseases' Forecasting systems are based on assumption about the pathogens' interactions with the host and environment, the disease triangle (Agrios, 2005). The objective is to accurately predict when the three factors – *host, environment* and *pathogen* – all interact in such a fashion that disease can occur and cause economic losses.

Good disease forecasting systems must be reliable, simple, cost effective and applicable to many diseases. As such they are normally designed for diseases that are irregular enough to warrant a prediction system, rather than diseases that occur every year for which regular treatment should be employed (Campbell and Madden, 1996). Forecasting systems may use one of the several parameters in order to work out disease risk, or a combination of factors (Esker *et al.,* 2008). One of the first forecasting systems designed was for *Steward's wilt* and based on winter temperature index as low temperature would kill the vector of the disease, so there would be no outbreak. An example of a multiple disease/ pest forecasting system is EPIdemiology, PREdiction and PREvention (EPIPRE) system developed in the Netherlands for winter wheat that focused on multiple pathogens (Reinink, 1986). Forecasting models are often based on a relationship like simple linear regression, where X is used to predict Y. Other relationship can be modelled using population growth curves (Esker *et al.,* 2008).

In the following segments, fungal airspora over crop fields in North East India are described as case studies. They are classified as cereals (rice, maize), pulses (broad bean, pea, common bean, black gram, soybean), vegetables (tomato, mustard, cabbage, potato) and cash crop (sugar cane, lemon).

CEREALS

Rice

The airspora study over paddy field in Guwahati (Assam) and their role in the sterility of rice revealed *Helminthosporium oryzae, Pyricularia oryzae, Ustilaginoidea verens* (Syn. *Claviceps oryzae sativae*), *Fusarium moniliforme* and *Trichoconis padwickii* as its pathogenic fungi (Chetia and Baruah, 1964). Various fungal types were also reported from the air, leaf surface and soil of paddy field in Shillong (Meghalaya) (Satpute *et al.,* 1987). The fungal airspora over rice field in Imphal (Manipur) revealed *Helminthosporium oryzae* Brada De Hanm (C.O. of Brown leaf spot, *Pyricularia oryzae* Cavara (C.O. of blast disease), *Claviceps oryzae sativae* (C.O. of false smut disease), *Trichoconis padwickii* (C.O. of stackburn disease). Comparisons were also made on the date of first incidence of spore in the air, date of first onset of disease, highest concentration, weather conditions, period of maximum incidence of spores and disease and the growth stages of the crop for different diseases of rice (Irabanta Singh, 1987).

Monitoring of airborne *Pyricularia oryzae* spores for two consecutive years (1988 and 1989) in Imphal revealed nocturnal pattern of diurnal periodicity with peak at 2.00 h. and absent during day time. Maximum concentration of *P. oryzae* conidia coincided with booting and panicle initiation stages of crop growth in October. Whereas panicle initiation and flowering stages occurred in November with high RH (90%) and moderate rainfall on the previous day. Longer dew period (more than 5 h.) and low night temperature (23^0C) helped in higher spore liberation during night hours. The concentrations of conidia were also affected by horizontal distance and vertical height from the source. Further, the intensity of blast infection was positively correlated with the number of conidia and infection in the crop (Irabanta Singh and Munanthoi Singh, 2000).

The fungal airspora over rice field in Thoubal district (Manipur) revealed three main diseases of rice, *viz.* false smut (C.O. *Claviceps oryzae sativae*), brown leaf spot (C.O. *Helminthosporium oryzae*) and blast disease (C.O. *Pyricularia oryzae*). The date of first onset of the false smut disease (C.O. *Claviceps oryzae sativae*) was recorded on 20th October in 2003 crop season whereas on 22nd October in 2004 crop season. The period of maximum incidence of spores and disease was recorded during 15th October to 20th November in 2003 crop season whereas 10th October to 25th November in 2004 crop season. The growth stage of the crop which coincided with the false smut disease was ripening to pre-harvest in both the crop seasons. The date of first onset of brown leaf spot disease (C.O. *Helminthosporium oryzae*) was recorded on 28th June in 2003 crop season whereas 30th June in 2004 crop season. The period of maximum incidence of the spore and brown leaf spot disease was booting to flowering in both the seasons. The date of first onset of the rice blast disease (C.O. *Pyricularia oryzae*) was recorded on 2nd July in 2003 crop season whereas 10th July in 2004 crop season. The period of maximum incidence of spores and blast disease were recorded during 20th June to 2nd September in 2003 crop season whereas 1st July to 10th September in 2004 crop season. The growth stage of the crop coincided with the blast disease of panicle initiation of flowering in both the crop seasons (Kamala Devi and Irabanta Singh, 2005).

Maize

The fungal airspora over a maize field in Senapati district (Manipur) during 1990 crop season revealed 43 fungal spore types. The pathogenic fungal types identified were *Helminthosporium, Cercospora, Puccinia, Sphacelotheca* and *Aspergillus.* These pathogens caused leaf blight, leaf spot, rust, smut and cob rot disease of maize crop and were detected over the maize field prior to the appearance of disease symptoms. The date of first onset of leaf blight disease (C.O. *Helminthosporium maydis*) was recorded on 10th June. The period of maximum incidence of spore was recorded during 20th May to 21st June which coincided with the growth stage of early cob formation. The date of first onset of leaf spot (C.O. *Cercospora sorghi*) was recorded on 20th June. The period of maximum incidence of spore was recorded during 19th May to 28th June, which coincided with the growth stage of early cob formation. The date of first onset of rust disease (C.O. *Puccinia sorghi*) was recorded on 21st June. The period of maximum incidence of spore was recorded during 25th April to 30th June which coincided with the growth stage of early cob formation. The date of first onset of smut disease (C.O. *Sphacelotheca realiana*) and cob rot disease (C.O. *Aspergillus fumigatus*) were recorded on 3rd June and 15th June respectively. The period of maximum incidence of spore for these two diseases were recorded during 13th April to 1st July and 10th April to 20th June respectively, which coincided with the growth stages of mid cob formation for both diseases (Irabanta Singh and Dorycanta, 1992).

PULSES

Broad beans

The fungal airspora over broad bean field for two consecutive crop seasons (1984-85 and 1985-86) in Imphal (Manipur) revealed leaf spot diseases (C.O. *Cladosporium cladosporoides, Alternaria brassicicola, A. solani, Cercospora zonata*) and leaf blight disease (C.O. *Alternaria alternata*). The date of first appearance of leaf spot of broad bean (C.O. *Cladosporium cladosporoides*) was recorded on 22nd September in 1984-85 crop season and the period of maximum incidence of disease was during October, 1984 to 1st week of January, 1985 in the growth stage of flowering. The date of first appearance of leaf spot of broad bean (C.O. *Alternaria brassicicola*) was recorded on 12th September during 1985-86 crop season and the maximum incidence was recorded during 30th October, 1985 to 22nd January, 1986 which coincided with the growth stage of pre-flowering stage. The date of first appearance of leaf blight (C.O. *Alternaria alternata*) was recorded on 21st December during 1984-85 crop season. The period of maximum incidence was recorded during 29th October, 1984 to 16th January, 1985 which coincided with the growth stage of flowering (Irabanta Singh and Rughumani Singh, 1988).

Pea

The fungal airspora over a pea field in Imphal (Manipur) during crop season (1985-86) revealed a variety of fungal spores. Among those spores, the pathogenic spores to the pea were downy mildew (C.O. *Peronospora pisi*), rust (C.O. *Uromyces fabae*), anthracnose (C.O. *Colletotrichum pisi*), powdery mildew (C.O. *Erysiphe polygoni*), leaf blight (C.O. *Alternaria* sp) and leaf spot (C.O. *Cladosporium* sp). The first onset on downy mildew, rust, anthracnose, powdery mildew, leaf blight and leaf spot for crop season 1985-86 were recorded on 2nd February, 1986; 1st December, 1985; 21st December, 1985; 27th December, 1985; 10th October, 1985; and 24th December, 1985 respectively. The period of maximum incidence of spores were February – April; January – February; January – March; February – April; December – February; and December – March respectively which coincided with various growth stages of the crop. During the second crop season 1986-87, the date of first onset of diseases were recorded on 15th January, 1987; 7th November, 1986; 1st March 1986; 17th November, 1986; 26th October, 1986 and 1st December, 1986 respectively. And the period of maximum incidence of spores were recorded during 11 – 23rd February; 5-17th February; 30th January – 11th February; 23rd February – 7th March; 12th January – 24th January and 25th December – 6th January, 1987 which coincided with various growth stages of the crop (Irabanta Singh, 1987 and 1988 – 89).

Common bean

The fungal airspora over a common bean field in Imphal for two consecutive crop seasons (1986 and 1987) revealed rust disease as a major disease of common bean in both the crop seasons. The causal organism was *Uromyces phaseoli.* The data of first onset of rust disease (C.O. *Uromyces phaseoli*) was recorded on 21st February during 1986 crop season whereas on 9th March during 1987 crop season. The period of maximum incidence of spores were recorded during 10th February to 10th April in 1986 whereas 11th March to 20th May in 1987 which coincided with growth stage of pre-flowering in 1986 crop season whereas flowering stage in 1987 crop season (Irabanta Singh and Sangbanabi Devi, 1998).

Black gram

The fungal airspora over a black gram field in Imphal West district (Manipur) for two consecutive crop seasons (1989 and 1990) revealed three important diseases *viz.,* leaf spot (*Colletotrichum* sp); Anthracnose (C.O. *Curvalaria* sp) and blight (C.O. *Fusarium* sp). The dates of first onset of leaf spot, Anthracnose and blight during 1989 crop season were recorded on 19th July; 13th August and 18th August respectively, whereas during 1990 crop season were on 20th July, 10th October and 13th August respectively. The highest concentration of *Colletotrichum* sp during 1989 and 1990 crop seasons were 20th September and 28th September respectively while that of *Curvularia* sp 23rd August and 8th August respectively and that of *Fusarium* sp were 24th August and 10th September respectively (Irabanta Singh and Kundala Devi, 1995).

Soybean

The fungal airspora over a soybean field in Imphal West district (Manipur) revealed two main diseases *viz.,* leaf spot (C.O. *Cercospora zonata*) and leaf rust (C.O. *Phakopsora pachyrhizi*). The date of first onset of leaf spot disease was recorded on 20th May, 2001. The period of maximum incidence of spore was recorded during 3rd April to 28th June, 2001 which coincided with growth stage of seedling. The date of first onset of leaf rust was recorded on 10th August, 2001 whereas the maximum incidence of spore was recorded during 4th August – 28th August, 2001. The growth stage of the crop was seedling (Irabanta Singh and Arunkumar, 2002).

VEGETABLES

Tomato

The fungal airspora over a tomato field in Imphal East district (Manipur) during 1989 crop season revealed two main diseases *viz.,* early blight (C.O. *Alternaria solani*) and late blight (C.O. *Phytophthora infestans*) respectively. The first onset of early blight was recorded on 10th January, 1989. The period of maximum incidence of spore was 10th January 1989 to 30th March, 1989 with growth period in vegetative stage. The first onset of late blight was recorded on 1st January, 1989. The period of maximum incidence of spores was 1st January to 1st February, 1989 which coincides with the growth stage pre-flowering (Irabanta Singh and Puneshwari Devi, 1991).

Mustard

The fungal airspora over the mustard field in Imphal West district (Manipur) conducted during two crop seasons (1985 and 1986) revealed four diseases *viz.,* mustard blight (C.O. *Alternaria brassicae*), white rust (C.O. *Albugo candida*), powdery mildew (C.O. *Erysiphe polygoni*) and downy mildew (C.O. *Peronospora brassicae*). There were close correlation between disease with weather conditions and growth stages of the crop. The date of first onset of mustard blight, white rust of crucifer, powdery mildew and downy mildew were recorded on 10th September, 27th September, 13th November and 21st November 1985 respectively. The period of maximum incidence of spores was recorded during 20th September to 2nd October, 1986; 18th January to 24th January, 1986; 19th December, 1986 and 25th December to 31st December, 1986 respectively. The growth stages of the crop were seedling, pre-harvest and grain formation respectively (Irabanta Singh, 1987 and 1991).

Cabbage

The fungal airspora over the cabbage field in Imphal East district (Manipur) during two crop seasons (1988 and 1989) revealed two diseases *viz.,* leaf spot (C.O. *Alternaria brassiciola*) and downy mildew C.O. *Peronospora parasitica*). The dates of first onset of these diseases were recorded on 13th November and 18th January during 1988 crop season, whereas on 16th December and 29th February during 1989 crop season respectively. The highest concentration of *Alternaria* spore which causes leaf spot disease was recorded on 25th February and 1st March for the first and second crop seasons respectively, while the *Peronospora* which causes downy mildew was recorded on 18th January and 29th February for the year 1988 and second 1989 crop seasons respectively (Irabanta Singh and Jibanlata Devi, 1991).

The fungal airspora over cabbage field in March (Chandel district, Manipur) four two consecutive crop seasons (January, 2012 to December, 2013) revealed 37 fungal types. Among them *Aspergillus fumigatus* occupied the highest (15.4%) followed by *Gliocladium penicilloides* (13.7%) and *Apergillus niger* (13.24%) and the lowest was *Drechslera* sp (0.18%). *Gliocladium penicilloides* was found as causal organism for yellowing and shriveling of cabbage leaves (Jayaluxmi, Dutta and Irabanta Singh, 2014).

Potato

The various fungal types were isolated from the air, leaf surface and soil of potato field in Shillong area, Meghalaya (Satepute, Dutta and Rao, 1987).

The fungal airspora over the potato field in Imphal East district (Manipur) (1987 and 1988, crop seasons) revealed two major diseases *viz.,* early blight of potato (C.O. *Alternaria solani)* and late blight of potato (C.O. *Phytophthora infestans*). The first onset of disease was recorded on 15th January and first incidence of the spore in the air was recorded on 5th November when the temperature was 24.81^0 C (max) and 3.23^0 C (min) for the first year crop season (1987). The first onset of early blight of potato disease was on 11th January and the first incidence of disease was recorded on 3rd November when the maximum temperature was 22.32^0 C and minimum temperature was 8.77^0 C for the second year (1988) crop season. The first incidence of late blight disease of potato in the crop season 1987 was recorded on 1st January and the first onset of disease in the air was recorded on 8th January. The first incidence of disease for 1988 crop season was recorded on 2nd January and the first onset of the disease was recorded on 10th January. The period of maximum incidence of spore for early blight was recorded during 15th January to 20th March, 1988 which coincided with the growth stage of vegetative to tuberization in both the crop seasons (1987 and 1988). The period of maximum incidence of spore for late blight was recorded during 8th January to 20th January in 1988 which coincided with the growth stage of vegetative to tuberization in both the crop seasons (Irabanta Singh, Tribeni Devi and Bhorot Singh, 1991).

The fungal airspora over potato plantation field in Imphal East district (Manipur) were carried out for two crop seasons (November 2010 to March, 2011 and November 2011 to March, 2012) which revealed 30 spore types. Deuteromycotina dominated the fungal airspora over the potato field during the investigation period. *Phytophthora infestans* was the causal organisms of late blight disease of potato. The disease affects leaves, stems and tubers. A total of 30 spore types belonging to 5 different sub-divisions of fungi were found from the potato field. The symptom of late blight disease of potato was noted first on foliage of the test crop in January for both the crop seasons. The period of maximum incidence of spore and disease was coincided with vegetation and tuberization phases of the crop (Bijaya Devi and Irabanta Singh, 2015).

CASH CROP

Sugarcane

The fungal airspora over sugar plantation in Sibsagar district (Assam) during 1987 crop season revealed low concentration of *Colletotrichum falcatum* conidia to the extent of 2.12% of the total catch (Ahmed and Baruah, 1976). Further the fungal airspora over a sugarcane field in Imphal West district (Manipur) revealed two main diseases *viz.,* red rot (C.O. *Colletotrichum falcatum*) and smut (C.O. *Ustilago scitaminea*). The date of first onset of red rot was recorded on 13th July, 1987. The period of maximum incidence of spore was recorded during 1st June to 25th June which coincided with vegetative growth stage. The date of first onset of smut disease was recorded on 7th June, 1987. The period of maximum incidence of spore was recorded during 1st July to 25th July which coincided with the vegetative growth stage. The highest concentration of *Colletotrichum* was recorded on 13th June, 1987 whereas the highest concentration of *Ustilago* spore was recorded on 13th July, 1987 (Irabanta Singh, Bacha Singh and Amita Devi, 1992).

Lemon

The fungal airspora over lemon orchard at Kachai in Ukhrul district (Manipur) for two crop seasons (May 2013 to April, 2015) revealed 33 fungal spore types. Emphasis was given to the occurrence of airborne fungal spores and the effect of meteorological parameters on their dissemination. The occurrence of fungal spores in the air was also correlated with changes in weather parameters. These studies were of great help in providing information to the farmers towards disease forecasting (Nimyaola and Irabanta Singh, 2016).

PLANT DISEASE MANAGEMENT STRATEGIES

Nowadays plant disease control is not practical and in most cases is not even possible. Indeed, we need not eliminate a disease, we merely need to reduce its progress and keep disease development below an acceptable level. Instead of plant disease control, we need to think in term of plant disease management (Irabanta Singh, 2009).

Plant disease epidemics can be classified into two types *viz.,* (i) Monocyclic and (ii) Polycyclics, depending on the number of infection cycles per crop cycle. The early stages of a monocyclic epidemic can be described quite well by a linear model, while the early stages of a polycyclic epidemic can be described with an exponential model. Since we are concerned with keeping diseases levels well below 100%, there is no need to adjust the models for approaching the upper limit, and we can use the simple linear and exponential models to plan strategies (Arneson, 2001). e.g.

Monocyclic Model			**Polycyclic Model**		
1	2	3	1	2	3
X = Q	R	T	$X = X_0 ert$		

Examining these models, we can see that in both there are three ways in which we can reduce X at any point in epidemic.

1. Reduce the initial inoculum (Q in the monocyclic model and X_0 in the polycyclic model). (Actually X_0 is the initial incidence of disease, which is proportional to the initial inoculum).
2. Reduce the rate of infection (R in the monocyclic model and *r* in the polycyclic model).
3. Reduce the duration of epidemic (the time, *t* at the end of the epidemics).

Thus, it can be used as three major strategies for managing plant disease epidemics and we can organize out plant disease control tactics under one or more of these strategies. Furthermore, by means of the model we can assess the quantitative impact of each strategy, not only by itself, but in its interaction with others.

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