Mini Review

Integrated Disease Management: Need for Climate-resilient Technologies

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Abstract

Effect of climate change on agriculture or more precisely on insect pests and diseases of agricultural crops is multidimensional. Magnitude of this impact could vary with the type of species and their growth patterns. The elevated agricultural production could be off-set partly or by plant pathogens. It is, therefore, important to consider all the biotic components under the changing pattern of climate. Research world over on the effect of climate change on diseases of crops is inadequate. Several diseases have been noted to be showing higher levels of infestation on different field and horticultural crops in India, which have been discussed. The article also looks at different strategies to cope with effects of climate change on diseases of crops with a proposal for *Integrated Decision Support System (IDSS) for Crop Protection Services* that suggests the operational focus, research priorities and aspects of capacity building, apart from the thrust on climate-resilient technologies.

Key words: agriculture, climate change, impact, pests

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Introduction

Climate change has become a household topic of discussion with more scientists getting involved in scientific research on the aspect while politicians are trying to derive mileage from the paradigm. The last decade of the 20th century and the beginning of the 21st century have been the warmest period in the entire global instrumental temperature record. Climate change is defined as any long-term significant change in the “average weather” that a given region experiences or in other words it is the shift in the average statistics of weather for long-term at a specific time in a specific region. Average weather may include temperature, precipitation and wind patterns. It involves changes in the variability or average state of the atmosphere over durations ranging from decades to millions of years. These changes can be caused by dynamic processes in earth-atmosphere system, external forces including variations in sunlight intensity due to solar flares or sun-spot cycle and by human activities. Climate change in the usage of the Intergovernmental Panel on Climate Change (IPCC) refers to 'a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties that persists for an extended period, typically for decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity' (IPCC 2007).

Increased emission of carbon dioxide (CO_2) and other greenhouse gases, predominantly methane (CH_4) and nitrous oxide (N_2O) have been ascribed as the main agents causing increase in global temperature. The second assessment report (AR2) of IPCC indicated that the increase in greenhouse gas concentrations leads to an additional warming of the atmosphere and the earth's surface. Concentration of CO_2 has increased from about 280 to almost 360 ppmv since preindustrial time, CH_4 from 700 to 1720 ppbv and N_2O from about 275 to about 310 ppbv. This development is ascribed to the magnitude of human intervention mostly in terms of fossil-fuel use, change in land-use pattern and agriculture. Global mean surface temperature has increased by 0.3-0.6 C since the late 19th century, a change that is unlikely to be entirely natural in origin. The temperature increase is widespread over the globe and is greater at higher northern latitudes (http://www.ipcc.ch). According to IPCC, cold days and cold nights have become less frequent and hot days, hot nights, heat waves more common. Rising temperature also affect the pattern of precipitation. Changes in rainfall pattern have already been noticed. The IPCC reports that the frequency of heavy precipitation has increased over most land areas, which is consistent with warming and increase of atmospheric water vapour. Based on the trends since 1900, precipitation significantly increased in eastern parts of North and South America, northern Europe and northern, central Asia whereas, declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Globally, the area affected by drought has increased since the 1970s.

Effect of climate change on agriculture or more precisely on insect pests and diseases of agricultural crops is multidimensional. Magnitude of this impact could vary with the type of species and their growth patterns. With the change in the temperature and rainfall pattern the natural vegetation over a region is facing a new phase of competition for survival. The fittest species are more likely to dominate in the changing pattern of climate. It may be assumed that the vegetation tolerating high temperature, salinity and having high CO_2-use-efficiency could fair better than other species. Any change in the managed vegetation system i.e. agriculture and forestry will directly affect the socio-economic implications of the regions involved. IPCC in its report of 1995 predicted that a double increase in the CO_2 level will increase yield by 30% in several crops. The elevated production could be off-set partly or entirely by the insect pest, pathogens or weeds. It is, therefore, important to consider all the biotic components under the changing pattern of climate. Parametric and non-parametric analysis of climatic data indicated that there was highly significant variation in some parameters for particular weekly averages across decades and over years for all the nine locations, which indicated that at those locations there has been significant change in climate for those parameters. Trends in climate variables for weekly, monthly and season wise were also obtined for different locations (Kumar et al 2012).

Climate change and plant disease scenario

World over research on effect of climate change on pests and diseases of crops is inadequate (Huda et al 2005). In India, there is limited effort in this area for any insect-pest or disease of any crop (Subba Rao et al 2007; Chattopadhyay and Huda 2009). However, at the genomic level, advances in technologies for the high-throughput analysis of gene expression have made it possible to begin discriminating responses to different biotic, abiotic stresses and potential trade-offs in responses. At the scale of the individual plant, enough experiments have been performed to begin synthesizing the effects of climate variables on infection rates, though pathosystem-specific characteristics make such synthesis challenging. At the population level, the adaptive potential of plant and pathogen populations may prove to be one of the most important predictors of magnitude of effects of climate change. Ecologists are now addressing the role of plant disease in ecosystem processes such as energy, mass fluxes and vice-versa vis-á-vis the challenge of scaling-up from individual infection probabilities to epidemics and broader impacts (Garrett et al 2006). Swaminathan (1986) indicated that the number of diseases on the same crops were much higher in tropics than under temperate conditions to indicate how rising temperatures could impact occurrence of plant diseases on agricultural crops. Presently, most of the work related to climate change vis-à-vis plant diseases is going on in rice (blast, bacterial leaf blight), wheat (*Puccinia, Septoria*) and horticultural crops (*Meloidogyne*). The trend indicates that severity of majority of diseases is found to be higher with elevated CO_2 levels (Chakraborty 2008), an off-shoot of climate change. It is also being opined that climate change could lead to a changed profile (variants) of pathogen, insect-pest ("climate change can activate 'sleeper' pathogens, whilst others may cease to be of economic importance" – Bergot et al 2004). The facultative pathogens with broad host range may survive better. There is also possibility of broadening of host range of the facultative pathogens. The need for further work in this area has been highlighted in adaptation experiments using twice-ambient CO_2, which increased the aggressiveness (Chakraborty and Datta 2003) and fecundity (Chakraborty et al 2000) of *Colletotrichum gloeosporioides*, which causes anthracnose of tropical legumes.

Scenario outside India

Elevated CO_2 may modify pathogen aggressiveness and/or host susceptibility and affect the initial establishment of the pathogen, especially fungi, on the host (Coakley et al 1999; Plessl et al 2005; Matros et al 2006). In most examples, host resistance has increased, possibly due to changes in host morphology, physiology and composition. Increased fecundity and growth of some fungal pathogens under elevated CO_2 has also been reported (Hibberd et al 1996; Coakley et al 1999; Chakraborty et al 2000). However, it has been reported that greater plant canopy size, especially in combination with humidity and increased host abundance, can increase pathogen load (Manning and Tiedemann 1995; Chakraborty and Datta 2003; Mitchell et al 2003; Pangga et al 2004). Sporulation by the pathogenic fungi could be 15 - 20 folds higher, leading to massive increase in the pathogen inoculum (Mitchell et al 2003). New strains may develop, with adaptation occurring faster and their evolution may get accelerated (Coakley et al 1999). Among the 27 diseases examined under elevated CO_2 levels, 13 caused higher crop losses than expected. Ten of the diseases had a reduced impact, and four had the same effect as they do now (NSW DPI 2007). With increased plant biomass at high CO_2 the stubble-borne fungal pathogen *Fusarium pseudograminearum* causing crown rot of wheat may become more severe (Melloy et al 2010). *Xanthomonas axonopodis* pv. *citri* was predicted to extend further south to major Australian citrus growing regions with a 1-5 C temperature increase (van Rijswijk et al unpublished). Analysis of archive samples from the Rothamsted long-term (since 1850s till

2010) wheat production and fertilizer experiment shows that historical records of SO_2 emissions are well correlated with the ratio of two pathogens (*Phaeosphaeria nodorum* / *Mycosphaerella graminicola*) (Fitt et al 2011).

Scenario within India

In India, yellow rust of wheat severity reached up to 100% with incidence being 30-40% in the terai and northern hills in 2010-11. Spot blotch (*Bipolaris sorokiniana*) has also become very important on wheat in recent times, which has been attributed to climate change. There is a severe occurrence of Indian Cassava Mosaic Virus in Kerala due to shift in climatic conditions; a new report of African Cassava Mosaic Virus, Sri Lankan Cassava Mosaic Virus is attributed to rise in temperature, CO_2 levels, according to plant pathologists (http://www.isppweb.org/nlnov10.asp#4). The Groundnut Bud Necrosis Virus (GBNV) has been taking toll of several field and horticultural crops across the country in recent times. The rise in temperature at Kanpur may have been beyond the tolerance limit of *Aceria cajani*, the mite vectoring Sterility Mosaic virus of pigeonpea, which could have influenced decline in the disease there. On the other hand, the weather factors might have shifted in favour of the vector at Bangalore that may have resulted in rise of the disease on the crop there. The climate variability may have also influenced Phytophthora blight incidence at Kanpur and Pantnagar in mutually opposite directions (Kumar et al 2012). Since report of Stemphylium blight on chickpea from Bangladesh in 1987, the disease has gradually moved to Nepal, India and now has been found infesting both lentil, chickpea in the North-Eastern Plain Zone, Terai region viz., Pantnagar and Pusa (Bihar) (Ghosh et al 2012). Contrastingly, Ascochyta blight, which used to be a major problem in chickpea in the North-Western Plains of India, has almost vanished from the area, which could also be due to substantial reduction in the area under the crop in the region and shift in the same towards southern India. Phyllody is being noticed on mungbean with up to 8% incidence (Mohapatra et al 2012).

Low solar radiation and short-day periodicity could result in higher infections by *Fusarium, Sclerotinia* and *Verticillium* (Nagarajan and Muralidharan 1995). Root rot is an emerging threat for rapeseed-mustard production system, recently reported from the farmers' field in some pockets of the country (Meena et al 2010), which was initially identified as stand-alone bacterial or fungal incidence or in combinations (*Erwinia carotovora* pv. *carotovora, Fusarium, Rhizoctonia solani* and *Sclerotium rolfsii*). Keeping in view that some isolates of *Alternaria brassicae* sporulated at 35C and several isolates had increased fecundity under higher RH (Goyal et al 2011), it seems that as per recent changes towards warmer and humid winters, being in line with current projections for future climate change (Waugh et al 2003), existence of such isolates could pose more danger to the oilseed Brassicas due to Alternaria blight. The immense variation available among only 13 representative isolates of *A. brassicae* also indicates their ability to adapt to varied climatic situations (Goyal et al 2011). In Germany, rapeseed-mustard pathogens such as *A. brassicae*, *Sclerotinia sclerotiorum* and others are predicted to be favoured by average warmer temperatures (Siebold and von Tiedemann 2012), which matches our observations.

Further, based on trends available related to cultural conditions favourable for different insect-pests and pathogens, we could be able to predict the possible changes likely to take place under changed conditions of climate apart from possible changes in host resistance, pest and pathogen fecundity. Higher carbohydrate concentration within host tissue of crops, particularly the C_3 ones, could promote development of a few biotrophic pathogens like rusts. Possibility of increase in dry root rot (*Rhizoctonia solani*) incidence in chickpea with prolonged high temperatures has been projected by scientists of ICRISAT. Due to rise in maximum temperature in post-rainy (*rabi*) season and shortening of cold period, powdery mildew incidence on chickpea (*Leveillula taurica*) in parts of southern India viz., northern Karnataka (Ghosh et al 2012) and on oilseeds *Brassica* (*Erysiphe cruciferarum*) has been observed appearing earlier (December) than usual time (late Jan, Feb) quite frequently in non-traditional crop growing areas of Madhya Pradesh, Haryana, central Uttar Pradesh, parts of Rajasthan and Bihar (Chattopadhyay et al 2012). There are indications for increase in sheath blight, sheath rot, false smut diseases of rice, fruit rot and die back of chilli, bitter gourd and potato, including post-harvest losses (Biswas 2011). In 2011 there has already been an upsurge in false smut incidence on rice crops in West Bengal (Ghosh et al 2012).

Global warming resulting in elevated carbon dioxide (CO_2) and temperature in the atmosphere could influence plant parasitic nematodes directly by interfering with their developmental rate, survival strategies and indirectly by altering host physiology. It may also influence free-living (microbial feeding) nematodes due to changes in quality and availability of food under enriched CO_2 conditions. Available information on effect of global warming on soil nematodes though limited, indicate that abundance of soil nematodes in general is either increased or unaffected by elevated CO_2 levels while individual species differ considerably in their response to climate change. Herbivorous nematodes showed neutral or positive response to CO_2 enrichment effects with some species showing the potential to build up rapidly and interfere with plant's response to global warming. Studies have also demonstrated that the geographical distribution range of plant parasitic nematodes may expand with global warming spreading nematode problems to newer areas (Somasekhar et al 2010). There are also reports of upsurge in infestation by *Rotylenchulus* and *Pratylenchus* on several crops viz., chickpea, vegetables etc.

Indian initiative

Presently, the India Meteorological Department (IMD, GoI) and the National Centre for Medium Range Weather Forecasting (NCMRWF) in coordination with scientists from other agencies, such as the Indian Council of Agricultural Research (ICAR) are regularly issuing location-specific weather forecast and agro-meteorological advisory as per different climatic conditions and cropping systems. ICAR recently launched National Initiative on Climate Resilient Agriculture (NICRA) in February, 2011 to boost research on the impact of climate change and its mitigation at national level. The project aims to enhance resilience of Indian agriculture to climate change, climate vulnerability through strategic research and technology demonstration. Research on adaptation and mitigation covers crops, livestock, fisheries and natural resource management. It also demonstrates site-specific technology packages on farmers' fields for adapting to current climate risks. This will certainly enhance the capacity of scientists and other stakeholders in climate resilient agricultural research and its application (http://www.icar.org.in). The mitigation of the adverse effect of climate is challenging. Acquaintances between pragmatic and modelling studies could prop-up swift advancement in perception, prediction of climate change effects.

The way forward

There are several insect-pest and disease forecasting networks across the globe viz., maize (EPICORN – for Southern corn leaf blight), tomatoes and potatoes (EPIDEM, TOMCAST, BLITECAST – for early and late blights), apple (Maryblight, EPIVEN – for fire blight and scab) etc. Further research advancement led to development of weather-based location-specific forewarning models based on multiple or stepwise regression, discriminant function analysis, artificial neural network for diseases (Desai et al 2004; Chattopadhyay et al 2005, 2011; Laxmi and Kumar 2011; Kumar 2013). These have been validated with success, even with issue of agro-advisories for public use.

At present, remote sensing (ISRO) data are also being used in generating weather forecasts, providing crop estimate in terms of net sown area and yield, issued in operational mode for the last few years with reasonable accuracy for rice, wheat, mustard and potato. Through an ICAR-ISRO (SAC) collaboration under MoA (DAC)-funded project FASAL (Forecasting Agricultural output using Space, Agrometeorological and Land-based observations), crop production has been forecasted at national level using multi-date temporal AWiFS (Advanced Wide Field Sensor on IRS-P6; 56 m x 56 m) and RADAR (RAdio Detection and Ranging) data. Two forecasts are made during the season at different crop growth stages. Encouraged by these successes, the IMD envisages implementation of FASAL initially at 46 centres, which is likely to be extended to 130 stations in due course (IMD 2013).

Use of remote sensing (RS) and Geographic Information System (GIS) could be explored for analysis of satellite-based agro-met data products, mapping geographical distribution of diseases and delineating the hotspot zones. Super-imposition with causative abiotic and biotic factors on visual pest maps can be useful for disease forecasting. Since, diseased plants increase reflectance particularly in chlorophyll absorption band (0.5-0.7 m) and water absorption bands (1.45-1.95m), forecasting plant disease is possible by remote sensing. Though information on this aspect is scanty, disease severity and yield loss estimation using changed reflectance pattern of diseased plants can be attempted. Remote sensing (greenness vegetation index derived from LANDSAT MSS digital data, four bands) has been successfully used to distinguish the healthy wheat in India from diseased wheat in Pakistan. Favourable weather from January to April and a sudden rise in temperature at mid-April are the main causes for yellow rust of wheat. Routine monitoring at surface for weather and by remote sensing could help predict epidemic well before first appearance of the disease on the crop, giving a positive edge to make accurate decision related to disease management. It has also been possible to detect Sclerotinia rot-affected mustard using remote-sensing technology (Dutta et al 2006; Bhattacharya et al 2007; Bhattacharya and Chattopadhyay 2013). These successful experiences could certainly be effective boosters for any future endeavour.

But the potential benefits of short-to-medium range weather forecast from numerical weather prediction (NWP) models or future climate projections have been least harnessed in India for regional crop protection services. Recent momentum to assimilate more updated satellite-based spatio-temporal atmospheric and land surface products (Bhattacharya 2013) from Indian geostationary satellites (Kalpana-1, INSAT 3A) for high resolution (5-15 km) weather forecasts from advanced NWP model such as WRF (Weather Research and Forecasters) is encouraging.

Such regular high-resolution forecast products are available for the registered users (http://www.mosdac.gov.in). A National Crop Forecasting Centre (NCFC) has been established at IARI, New Delhi under the behest of MoA (DAC) and ISRO. Therefore, an *Integrated Decision Support System (IDSS) for Crop Protection Services* (Fig. 1) can be imagined with its evolution in a phased manner, which could have the following three components:

(A) Operational focus (with periodic production of alarm zones encompassing 127 agro-climatic zones through well-tested models, forecast weather, high-resolution remote sensing data and operational crop map in the GIS framework),

(B) Research priorities on:

(i) development of forecast models for major insect-pests and diseases with large-scale applicability, validation in farmers' fields and model refinements,

(ii) field-to-satellite-based remote sensing with high-resolution observations to differentiate biotic stresses from abiotic stresses (moisture and nutrients), normal health, and

(iii) development of models for minor pests and diseases in view of climate change scenario.

(iv) development of crop loss models.

(v) initiation of studies on pest and disease development with changing microclimatic regime and processes.

(C) Human Resources renewal:

(i) creation of experts on handling of spatial data, who could be brave enough to think differently, bold enough to believe that as a team they could bring a positive change in the present practices of pest management and talented enough to do it,

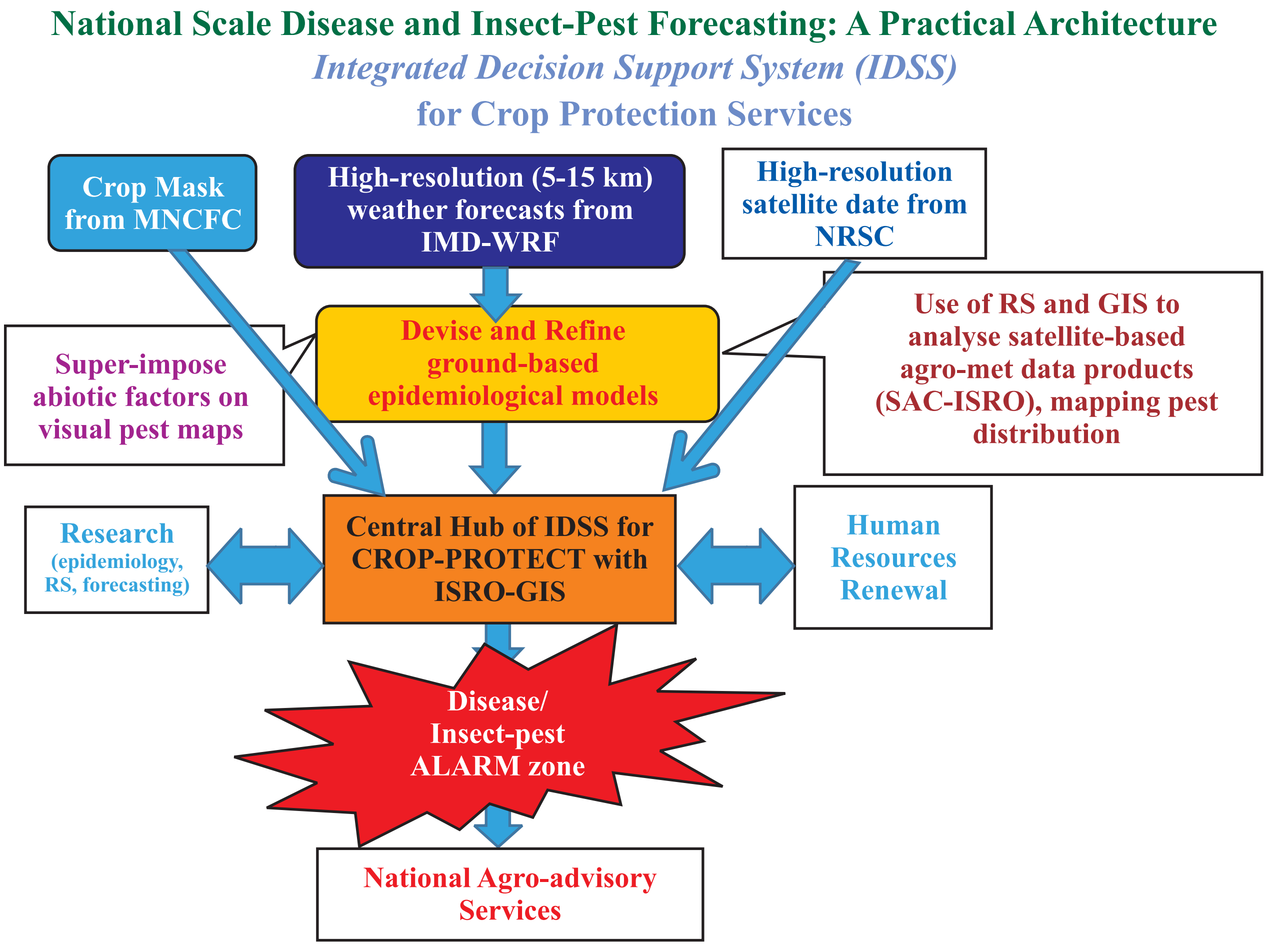

Figure 1. Proposed architecture of Integrated Decision Support System for Crop Protection Services (modified from Ghosh et al 2012)

(ii) familiarization of policy makers with more of digital products for interpretation and (iii) regular feedback mechanism from farmers through Village Resources Centre (VRC) network using satellite communication.

On-line decision support systems to forecast different diseases are in use across the globe for tan spot, septoria leaf blotch, leaf rust and Fusarium head blight /scab diseases of wheat (http://www.ag.ndsu.edu/ndsuag/features/small-grain-disease-forecasting), canola light leaf spot (*Pyrenopeziza brassicae* on http://www.rothamsted.bbsrc.ac.uk/Research/Centres/Content.php?Section=Leafspot&Page=llsforecast) and Phoma stem canker (*Leptosphaeria maculans, L. biglobosa* on http://www.rothamsted.bbsrc.ac.uk/Research/Centres/Content.php?Section=Leafspot&Page=phomaforecast). Models of plant disease have now been developed to incorporate more sophisticated climate predictions.

In view of changing climate, the devised and to-be-born models need to be oriented to dynamic mode. The models already developed are based on some observations on meteorological parameters, diseases recorded in the past and hence are based on previous disease-weather correlation. However, with change in climate, the disease-weather relationship is also bound to change apart from behaviour of the hosts, newer varieties, cropping practices, etc. (Chakraborty et al 2008). Importance of decision support systems have been highlighted by several workers (Rossi et al 2012). Multiple, interconnected processes will require interdisciplinary science, long-term funding and the increased use of meta-analysis (Kozlov and Zvereva 2011). At the same time, there is a need for catching up with the latest scientific developments viz., networking in epidemiology and disease forecasting and digital pest diagnostics and severity estimation to improve dissemination of knowledge in plant health (Bock et al 2010; Norton and Taylor 2010). Many reviews available on the topic of plant diseases and climate change agree that there is a need for more empirical data on the subject (Chakraborty and Newton 2011). The assumption is that more and better data will make prediction more accurate and/or reliable (Shaw and Osborne 2011). Dynamic models incorporate the recorded data of each crop season for a particular pest to suitably revise itself and thus remain stable, relevant enough to continue providing accurate forecast.

But due to inadequacies in hard-core data, the vital questions still haunt – what are the possible impacts of climate change on diseases and insect-pests of major crops or any shift in pathogen status with change of climate in the agro-ecological region growing major crops in India? We may have seen some changes in scenario of insect-pests, pathogens and ascribed them to changed climatic patterns. However, establishing such correlation through research remains to be done in India.

The technique in System of Rice Intensification is reported to have helped 55-70% reduction in major diseases of the crop in Vietnam during 2005-06 (Uphoff 2007), which seems an effective strategy to cope with the effects of climate change. Similar efforts would be warranted to adapt to and manage the effects of climate change on pests and diseases of different crops. Prediction and management of climate change effects on plant health are complicated by indirect effects and the interactions with global change drivers. Uncertainty in models of plant disease development under climate change calls for a diversity of management strategies, from more participatory approaches to interdisciplinary science (Pautasso et al 2012). Accordingly, there could be a pro-active approach to breed for resistance to pests, pathogens and their variants likely to be dangerous apart from modelling the future possible pest and disease scenario in major crops. Monitoring of variability in major insect-pests, pathogens and nematodes affecting agricultural crops to keep track of upheaval of 'sleeper races' becoming severe under changed climate, modelling future enemies of plants and designing crops with resistance to such would-be menaces as also modifying IPM strategies suitably to enable them be more climate-resilient may need emphasis.

Today's challenge is to 'produce more from less'. In the era of climate change, diagnostics of pests and diseases and capacity building of farmers, extension and even research personnel for adaptation to changed pest scenario under future climates assumes significance, wherein Integrated Crop Management in Private-Public-Partnership mode could be very effective. Farmers' decisions are of vital importance for good yields of crops. Forecasted weather products and area-wide weather networks are becoming more prevalent. Now, the challenge is to bring continuous improvement in productivity, profitability, stability and sustainability of major farming systems, wherein scientific management of plant pests holds a pivotal role (Swaminathan 1995). Crop loss models, representing a dynamic interaction between pests and host, are essential for forecasting losses thereof. Accurate information concerning possible yield losses due to occurrence of a pest is needed by growers or plant protection specialists to decide on cost-effective control measures. With an increasing concern for cleaner environment and discouragement for pesticide use, there is need to approach pest management through knowledge on their dynamics as an art of living with them (Zadoks 1985). Thus, future research and education in Plant Pathology in India does need to address the issue of future climates in pest management, for which fund requirement would certainly be lesser than many ambitious ones.

References

AICRPP (All India Coordinated Research Project on Pigeonpea)**.** 2008, 2009. *Annual Report*. Indian Institute of Pulses Research, Kanpur.

Bergot M, Cloppet E, Pérarnaud V, Déqué M, Marçais B and Desprez-Loustau ML. 2004. Simulation of potential range expansion of oak disease caused by *Phytophthora cinnamomi* under climate change. *Global Change Biology* 10: 1-14.

Bhattacharya BK. 2013. Remote sensing of land surface states for weather forecasting. *Signatures* (in press).

Bhattacharya BK and Chattopadhyay C. 2013. A multi-stage tracking for mustard rot disease combining surface meteorology and satellite remote sensing. *Computers Electronics Agriculture* 90: 35-44.

Bhattacharya BK, Chattopadhyay C, Dutta S, Meena RL, Roy S, Parihar JS and Patel NK. 2007. Detection of Sclerotinia rot incidence in Indian mustard from polar orbiting satellite platform. In: *Proceedings, 12th International Rapeseed Congress, Vol. IV* (Plant Protection), Wuhan, China, 26-30 Mar 2007, Fu Tingdong and Guan Chunyun (eds.), Science Press USA Inc., pp 79-83.

Biswas A. 2011. Plant diseases in the perspective of climate change. *SATSA Mukhopatra –Annual Tech Issue* 15: 84-86.

Bock C H, Poole G H, Parker P E and Gottwald T R. 2010. Plant disease severity estimated visually, by digital photography and image analysis, and by hyperspectral imaging. *Critical Rev Plant Sci* 29: 59–107.

Chakraborty S. 2008. Meeting Sukumar Chakraborty. *ICPP Newsletter* 4: 2.

Chakraborty S and Datta S. 2003. How will plant pathogens adapt to host plant resistance at elevated CO2 under a changing climate? *New Pathologist* 159: 733-742.

Chakraborty S and Newton A C. 2011. Climate change, plant diseases and food security: an overview. *Plant Pathol* 60: 2–14.

Chakraborty S, Luck J, Hollaway G, Freeman A, Norton R, Garrett KA, Percy K, Hopkins A, Davis C and Karnosky DF. 2008. Impacts of global change on diseases of agricultural crops and forest trees. *CAB Reviews: Perspectives in Agriculture, Veterinary Sciences, Nutrition and Natural Resources* 3: 1-15.

Chakraborty S, Pangga IB, Lupton J, Hart L, Room PM and Yates D. 2000. Production and dispersal of *Colletotrichum gloeosporiodies* spores on *Stylosanthes scabra* under elevated CO_2. *Environmental Pollution* 108: 381-387.

Chattopadhyay C. and Huda AKS. 2009. Changing climate forcing alteration in cropping pattern to trigger new disease scenario in oilseeds and pulses in Indian sub-continent. In: Abstracts, National Symposium on Climate Change, Plant Protection, Food Security Interface, Kalyani, 17-19 Dec 2009, pp. 70.

Chattopadhyay C, Agrawal R, Kumar A, Bhar LM, Meena PD, Meena RL, Khan SA, Chattopadhyay AK, Awasthi RP, Singh SN, Chakravarthy NVK, Kumar A, Singh RB and Bhunia CK. 2005. Epidemiology and forecasting of Alternaria blight of oilseed *Brassica* in India – a case study. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz* 112: 351-365.

Chattopadhyay C, Agrawal R, Kumar A, Meena R L, Faujdar K, Chakravarthy NVK, Kumar A, Goyal P, Meena PD and Shekhar C. 2011. Epidemiology and development of forecasting models for White rust of *Brassica juncea* in India. *Arch Phytopath Plant Prot* 44: 751-763.

Chattopadhyay C, Bhattacharya BK, Kumar V, Kumar A and Meena PD. 2012. Impact of climate change on pests and diseases of oilseeds *Brassica* – the scenario unfolding in India. *J Oilseed Brassica* 2: 48-55.

Coakley SM, Scherm H and Chakraborty S. 1999. Climate change and plant disease management. *Annu Rev Phytopathol* 37: 399–426.

Desai AG, Chattopadhyay C, Agrawal R, Kumar A, Meena RL, Meena PD, Sharma KC, Rao MS, Prasad YG and Ramakrishna YS. 2004. *Brassica juncea* powdery mildew epidemiology and weather-based forecasting models for India – a case study. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz* 111: 429-438.

Dutta S, Bhattacharya BK, Rajak DR, Chattopadhyay C, Patel NK and Parihar JS. 2006. Disease detection in mustard crop using EO-1 hyperion satellite data. *J. Indian Soc. Remote Sensing (Photonirvachak)* 34: 325-329.

Fitt BDL, Fraaije BA, Chandramohan P and Shaw MW. 2011. Impacts of changing air composition on severity of arable crop disease epidemics. *Plant Pathol* 60: 44–53.

Garrett KA, Dendy SP, Frank EE, Rouse MN. and Travers SE. 2006. Climate change effects on plant disease: Genomes to ecosystems. *Annu Rev Phytopathol* 44: 489–509.

Ghosh A, Das A, Bhattacharya BK, Kumar V, Kumar A, Meena PD and Chattopadhyay C. 2012. Impact of Climate Change on Pests and Diseases - the Scenario Unfolding in Indian Agriculture. *SATSA Mukhopatra Annual Technical Issue* 16: 15-29.

Goyal P, Chahar M, Mathur AP, Kumar A and Chattopadhyay C. 2011. Morphological and cultural variation in different oilseed *Brassica* isolates of *Alternaria brassicae* from different geographical regions of India. *Ind J Agri Sci* 81: 1052-1058.

Hibberd JM, Whitbread R and Farrar JF. 1996. Effect of elevated concentrations of CO_2 on infection of barley by *Erysiphe graminis*. *Physiol Mol Plant Path* 48: 37-53.

Huda AKS, Spooner-Hart R, Murray G, Hind-Lanoiselet T, Ramakrishna YS, Desai S, Thakur RP, Chattopadhyay C, Jagannathan R, Khan SA and Rathore LS. 2005. Climate related agricultural decision making with particular reference to plant protection. *J Mycol Pl Pathol* 35: 513.

IMD (India Meteorological Department). 2013. Future projections in AAS. Retrieved from http://www.imd.gov.in/services/agri_new/Activities.htm on 15 Feb 2013 at 1242 hrs IST.

IPCC 2007. Fourth Assessment Report: Climate Change. Downloaded from http:// www.ipcc.ch on 17 Feb 2013 at 2216 hrs IST.

Kozlov M V and Zvereva E L. 2011. A second life for old data: global patterns in pollution ecology revealed from published observational studies. *Environmental Pollution* 159: 1067–1075.

Kumar A. 2013. Forewarning models for Alternaria blight in mustard (*Brassica juncea*) crop. *Ind J Agri Sci* 81: 116-119.

Kumar A, Chattopadhyay C, Singh KN, Vennila S and Rao VUM. 2012. Trend analysis of climate variables for pigeonpea growing area. In: Abstract, International Conference on Statistics and Informatics in Agricultural Research, organised by ISAS at New Delhi, 18-20 Dec 2012, pp 100-101.

Laxmi RR and Kumar A. 2011. Forecasting of powdery mildew in mustard (*Brassica juncea*) crop using artificial neural networks approach. *Ind J Agric Sci* 81: 855–860.

Manning W and Tiedemann A. 1995. Climate change: Effects of increased atmospheric carbon dioxide (CO2), ozone (O3), and ultraviolet-B (UV-B) radiation on plant diseases. *Environmental Pollution* 88: 219-245.

Matros A, Amme S, Kettig B, Buck-Sorlin GH, Sonnewald U and Mock HP. 2006. *Growth at elevated CO_2 concentrations leads to modified profiles of secondary metabolites in tobacco cv. SamsunNN and to increased resistance against infection with potato virus Y. Plant, Cell and Environment* 29: 126-137.

Meena PD, Awasthi RP, Chattopadhyay C, Kolte SJ and Kumar A. 2010. Alternaria blight: a chronic disease in rapeseed-mustard. *J Oilseed Brassica* 1: 1-11.

Melloy P, Hollaway G, Luck J, Norton R, Aitken E and Chakraborty S. 2010. Production and fitness of *Fusarium pseudograminearum* inoculum at elevated carbon dioxide in FACE. *Global Change Biology* 16: 3363-3373.

Mitchell CE, Reich PB, Tilman D and Groth JV. 2003. Effects of elevated CO_2, nitrogen deposition, and decreased species diversity on foliar fungal plant disease. *Global Change Biology* 9: 438-451.

Mohapatra SD, Chattopadhyay C and Ghosh A. 2012. Occurrence of mungbean phyllody and its management. *J Mycol Pl Pathol* 42: 38 (Abstr).

Nagarajan S and Muralidharan K. 1995. *Dynamics of Plant Diseases*, Allied Publ. Ltd., New Delhi, 247 p.

Norton G and Taylor M. 2010. What pest is that? Recent developments in digital pest diagnostics. *Outlooks on Pest Management* 21: 236–238.

NSW Department of Primary Industries. 2007. Editor's Note: Science Alert. 02 March 2007 http://www.sciencealert.com.au/news/20070203-13999.html

Pangga IB, Chakraborty S and Yates D. 2004. Canopy size and induced resistance in *Stylosanthes scabra* determine anthracnose severity at high CO_2. *Phytopathology* 94: 221-227.

Pautasso M, Döring TF, Garbelotto M, Pellis L and Jeger MJ. 2012. Impacts of climate change on plant diseases—opinions and trends. *European J Plant Pathol* DOI 10.1007/s10658-012-9936-1.

Plessl M, Heller W, Payer HD, Elstner EF, Habermeyer J and Heiser I. 2005. Growth parameters and resistance against *Drechslera teres* of spring barley (*Hordeum vulgare* L. cv. Scarlett) grown at elevated ozone and carbon dioxide concentrations. *Plant Biology* 7: 694-705.

Rossi V, Caffi T and Salinari F. 2012. Helping farmers face the increasing complexity of decision-making for crop protection. *Phytopath M* 51: 457−479.

Shaw MW and Osborne TM. 2011. Geographic distribution of plant pathogens in response to climate change. *Plant Pathol* 60: 31–43.

Siebold M and von Tiedemann A. 2012. Potential effects of global warming on oilseed rape pathogens in Northern Germany. *Fungal Ecology* 5: 62–72.

Somasekhar N, Prasad JS and Ganguly AK. 2010. Impact of Climate Change on Soil Nematodes - Implications for Sustainable Agriculture. *Ind J Nemat* 40: 125-134.

Subba Rao AVM, Agarwal PK, Huda AKS. and Chattopadhyay C. 2007. Using InfoCrop –A user friendly crop simulation model for mustard. In: *Climate and Crop Disease Risk Management – An International Initiative in Asia Pacific Region*. CRIDA, Hyderabad, pp 16.

Swaminathan MS. 1986. Changing paradigms in Indian agriculture – the way ahead. *The Hindu*, pp 22-46.

Uphoff N. 2007. Reducing the vulnerability of rural households through agroecological practice: considering the System of Rice Intensification (SRI). *Mondes en Developpment* 35: 85-100.

Waugh MM, Kim DH, Ferrin DM and Stanghellini ME. 2003. Reproductive potential of *Monosporascus cannonballus*. *Plant Dis* 87: 45–50.

Zadoks, J.C. 1985. On the conceptual basis of crop loss assessment: the threshold theory. *Annu Rev Phytopathol* 23: 455-473.

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