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Weather Based Forewarning of Pest and Disease: An Important Adaptation Strategies Under The Impact of Climate Change Scenario: A Brief Review

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ABSTRACT

The intergovernmental panel on climate change predicts the current emission scenario; the global mean temperature would rise between 0.9 and 3.5^{OC} by the year 2100. It may be affects pest, disease and plants and is likely to make plants more vulnerable to infectious disease, which cause reduces the yield of agricultural crop. Some other problem is also generated due to climate change such as new pest and disease complexes may arise and some pest and diseases may cease to be economically important if warming causes a pole ward shift of agro climatic zones and host plant migrate into new regions. Disease triangle is a conceptual model that shows the interactions between the weather, host and pathogen. These three components are essential for appearance of crop insect pest, disease and favorable of weather condition, crop stage and occurrences of pathogen (all three conditions) are responsible its severity. Pest/disease infestation in crops is highly influenced by meteorological parameters such as mean maximum temperature, mean minimum temperature, mean temperature, mean morning relative humidity, mean evening relative humidity, mean relative humidity, total rainfall, mean wind speed and mean bright sunshine hour etc.

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Introduction

On the basis of weather and pest interaction (iterative approach) some scientist and institute are developed weather based prediction rule and find congenial weather for outbreak and intensities of crop pest and diseases. The weather based forewarning and modeling of pest and disease for early warning of pest/disease outbreak/infestation may provide appropriate tools for investigating and predicting pest/disease status (high, moderate and low). Pest surveillance and forewarning of insect pest and disease are the key component of crop protection strategies under the impact of climate change scenario. It reduces the cost of production by optimizing the timing and frequency of application of pest management measures and ensures operator, consumer and environmental safety by reducing chemical usage. Some institute such as Indian Agricultural Statistical Research Institute (IASRI), India Meteorological Department (IMD) and National Centre for Integrated Pest Management (NCIPM) plays an important role for forewarning of insect pest and disease and communicate it farmer level. The main focus of the current review paper is to find out the scenario of crop pest under climate change and congenial weather condition for the outbreak and intensities of crop pest and diseases.

Climate is a key driver of most insect-pests, disease, and a changing climate will alter the distribution, abundance and management of endemic pests and disease (**Chakraborty 2005**). According to **IPCC**'s latest report, global mean temperature would rise between 0.9 and 3.5ºC by the year 2100. The classic pest and disease triangle recognizes the role of climate in plant, insect pest diseases as no virulent pathogen can induce disease in a highly susceptible host if climatic conditions are not favorable. Climate influences all stages of host and pathogen life cycles as well as development of disease. Pest and disease severity over a period can fluctuate according to climatic variation (**Mina and Sinha, 2008**).

Forewarning refers to the prediction of forthcoming infestation of the pest in numbers which would cause economic damage to the crop. It is of foremost importance in integrated pest management program as it serves as a tool to remain in preparing to face the exigencies. Weather based pest and disease forecast models are used in crop protection. For the purpose of development and use of these models, both meteorological and biological data are required as input, while the output is the anticipated outbreak of pest or disease. (**Lingappa *et al* 2003**).

Climate change has the potential to modify host physiology and resistance and to alter the stages and rates of development of the pest and pathogen. The most likely impacts would be shifted in the geographical distribution of the host, pest and pathogen, change in the physiology of host-pest and pathogen interactions and change in crop losses. New pest and disease complexes may arise and some pest and diseases may cease to be economically important if warming causes a pole ward shift of agro climatic zones and host plant migrate into new regions. The pathogen would be following the migrating hosts and may infect vegetation of natural plant communities not previously exposed to the often more aggressive strains of agricultural crops. The mechanism of pest and pathogen dispersal, suitability of the environment for dispersal, survival between seasons, and any change in host-physiology and ecology in the new environment will largely determine how quickly pest and pathogens become established in a region.

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Change may occur in the type, amount, and relative importance of pest/pathogens and affect the spectrum of pest/disease affecting particular crop. Plants growing in marginal climates could experience chronic stress that would predispose them to insect and disease outbreaks (**Mina and Sinha, 2008**).

Table 1. Recorded instances of recent insect pest outbreaks in relation to the changing climate scenario in India

Insect pest	Order/ Family	Host plant/ s	Region/ location	Probable reason/ s	Impact of pest outbreak	Reference
Sugarcane woolly aphid *Ceratovacuna lanigera* Zehntner	Hemiptera: Aphididae	Sugarcane	Sugarcane belt of Karnataka and Maharashtra States during 2002-03	* Recent abnormal weather patterns * Insecticide misuse	* 30% yield losses * Reduced cane recovery	Joshi, and Viraktamath, 2004; Srikanth, 2007
Rice plant hoppers *Nilparvata lugens* (Stal) and *Sogatella furcifera*(Horvath)	*Hemiptera: Fulgoridae*	Rice	North India	- do-	* Crop failure over more than 33,000 ha paddy area	IARI News, 2008 IRRI News, 2009
Mealy bug, *Phenacoccus solenopsis* Tinsley	*Hemiptera: Pseudococcidae*	Cotton, Vegetables and ornamentals	Cotton growing belt of the country	* Recent abnormal weather patterns * Insecticide misuse *Changed cropping environment(introduction of Bt cotton)	* Heavy yield (30-40%) loss to the cotton *Increased cost of crop protection due to overuse of pesticides	Dhawan *et al.*, 2007
Papaya mealy bug *Paracoccus marginatus*	Hemiptera: Pseudococcidae	Papaya	Tamil Nadu, Karnataka, Maharashtra	*Recent abnormal weather patterns *Insecticide misuse	*Significant yield loss to the papaya growers	Tanwar *et al.*, 2010

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Table 2. Published reports of empirical studies on impact of climate change on future geographic range and distribution of insect pests.

Insect pest	Order/ Family	Host plant/s	Impact on insects/ behavioural response	Reference
Corn earworms *Heliothis zea* (Boddie) and *Helicoverpa armigera* (Hubner)	Lepidoptera: Noctuidae	Maize	*Altitudes wise range expansion and increased overwintering survival in USA	Diffenbaugh *et al.*, 2008
European corn borer *Ostrinia nubilalis*		Maize	* Northward shifts in the potential distribution up to 1220 km are estimated to occur * An additional generation per season	Porter *et al*, 1991
104 common microlepidoptera species inhabitant in Netherlands	Lepidoptera	Many crops of agricultural importance	Changing patterns in phenology and distribution of microlepidoptera in the Netherlands *Advancement of flight peak dates almost by 12 days since 1975-1194 *Changes in the species composition of the local fauna	Kuchlein and Ellis, 1997
Old world Boll worm *Helicoverpa armigera* (Hubner)			Phenomenal increase in the United Kingdom from 1969-2004 and outbreaks at the northern edge of its range in Europe	Cannon, 1998
Cottony cushion scale *Icerya purchasi*			* Populations appear to be spreading northwards	Cannon, 1998
Oak processionary moth *Thaumetopoea processionea*			*Northward range extension from central and southern Europe into Belgium, Netherlands and Denmark	Cannon, 1998
Cottony camellia scale *Chloropulvinaria floccifera*			*More abundant in the United Kingdom, * Extending its range northwards in England and increasing its host range in the last decade	Cannon, 1998
35 species of non migratory European butterflies	Papilionidae, Lycaenidae, Nymphalidae, Satyrinae		* Pole ward shift of the geographic range and distribution	Parmesan and Yohe, 2003
Cotton	Lepido	Cotton	* Expansion of geographic range	Sharma *et al.*, 2005; 2010

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bollworm/ Pulse pod borer *Helicoverpa armigera* (Hubner)	ptera: Noctuidae	, Pulses, vegetables	in Northern India *Adult flights/ migratory behavior	

Effect of Elevated Carbon Dioxide on Crop, Pest Dynamics

A larger crop canopy and denser foliage resulted from enhanced CO_2 level in the atmosphere will create more relative humidity, thereby making the micro - environment more favorable for pests. Increases in food quality, i.e. increase in the nitrogen content of plants due to high temperature, can result in a sudden resurgence of population of pests. Moreover, under condition of stress, plant defensive systems are less effective and they become more susceptible to pest attack (**Coviella and Trumble 1999**). Some more findings on the effects of enhanced CO_2 on crop pests are given in the table 1.

Table 1. Effect of increasing atmospheric carbon dioxide on plant, insect interaction.

Increasing atmospheric carbon dioxide leads to	**References**
Increasing... Food consumption by caterpillars Reproduction of aphids Predation by lady beetle Carbon based plant defenses Effect of foliar application and *B.thuringiensis*	Osbrink *et al.*, 1987 Bezemer *et al.*, 1999 Chen *et al.*, 2005 Coviella and Trumble, 1999 Coviella and Trumble, 2000
Decreasing... Insect development rates Response to alarm pheromones by aphids Parasitism Effect of transgenic *B. thuringiensis* Nitrogen-based plant defense	Osbrink *et al.*, 1987 Awmarck *et al.*, 2000 Roth and Lndroth, 1995 Coviella *et al.*, 2000 Coviella and Trumble, 1999

Impact of Enhanced Temperature on Crop, Pest Dynamics

Insects are cold-blooded organisms – the temperature of their bodies is approximately the same as that of the environment. Therefore, temperature is probably the single most important environmental factor influencing insect behavior, distribution, development, survival, and reproduction. Some researchers believe that the effect of temperature on insects largely overwhelms the effects of other environmental factors (**Bale *et al.*, 2002**). It has been estimated that with a CO_2 temperature increase, insects might experience one to five additional life cycles per season (**Yamamura and Kiritani 1998**). Other researchers have found that moisture and CO_2 effects on insects can be potentially important considerations in a global climate change, setting (**Coviella and Trumble 1999**; **Hunter 2001**). For every insect species there is a range of temperature within

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which it remains active from egg to adult stage. Lower values of this range are called 'threshold of development' or 'developmental zero'. Within the favorable range, there is an optimum temperature at which most of the individuals of a species complete their development. Exposure to temperatures on either side of the range exerts an adverse impact on the insect by slowing down the speed of development. The possible impacts of increased atmospheric temperature on crop pests found by other researchers are summarized in table 2.

Table 2 Effect of enhanced atmospheric temperature on crop pest dynamics

Increasing atmospheric temperature leads to	**Reference**
Increasing... Northward migration Migration up elevation gradients Insect developmental rates and oviposition Potential for insect outbreaks Invasive species introductions Insect extinctions	Parmesan, 2006 Epstein *et al.*, 1998 Regniere, 1983 Bale *et al.*, 2002 Dukes and Mooney, 1999 Thomas *et al.*, 2004
Decreasing... Effectiveness of insect biocontrol by fungi Reliability of economic threshold levels Insect diversity in ecosystems Parasitism 1995	Stacy and Fellowes, 2002 Trumble, John and Butler, Casey, 2009 Erasmus *et al.*, 2002 Hance *et al.*, 2007; Fleming and Volney,

Role of India Meteorological Department for forewarning of crop pest outbreak

Every year crops are being damaged by pests and diseases. Due to lack of proper operational forecasting system for the incidences of pests and diseases, it becomes difficult to adopt plant protection measures at right time. It has been established with a fair degree of accuracy that climate/weather plays major role in the incidences of pests and diseases. Thus, there is great scope of utilizing meteorological parameters for the advance information about the occurrences of pests and diseases and ultimately scheduling of prophylactic measures can be taken scientifically and judiciously. Quite a number of studies on the relation between meteorological parameters and pest and disease incidences have already been made in India. **(Chattopadhyay, N *et.al, 2011*)** Weather based pests and disease models to dissemination of the advance information to the farmers through different state of the art information technology, are being taken to control and minimize the loss of crops due to pests and disease incidences.

Meteorological Department plays an important role for prediction of crop pest with the help of location specific research center historical data of crop pest and climate. On the basis of historical data on weather and crop pest find the congenial weather condition for an outbreak of crop pest on the specific location. The feasibility of meteorological forewarning of aphid, jassid, thips, mird and pink bollworm of cotton. A critical analysis of correlation coefficients between the light trap catches of gall midge and stem borer of rice and meteorological parameters showed that there are turning points and epicenters of outbreak of both the pests. The study also revealed that maximum and minimum temperature, morning and afternoon relative humidity, bright sunshine hours and weekly total rainfall have a profound

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effect on the development of gall midge and stem borer at their successive generations. Due to variation in weather parameters within the season and inter season between *kharif* and *rabi* the maximum peaks of gall midge and stem borer infestations were observed respectively in *kharif* and *rabi* seasons. Favorable weather conditions for the development of gall midge and stem borer at each of the generations were worked out and discussed.

Weather based forewarning models/guidelines for the peak infestation period for important pests of major crops were developed. Pest weather calendars for important pests were also prepared for operational crop protection. These pest, weather calendars, present and forecast weather and pest observations from the field would help the Agromet Advisory Units of IMD to issue forewarning of pest outbreak and also to advise the farming community to decide their spraying and dusting operations. An attempt has been made to use operational pests and diseases management scheme which not only reduce the damage lower than the economic injury level, but also support the growth and survival of its natural enemies. The need to minimize the use of noxious chemicals through proper application of the right chemicals at the right time using weather based information has been emphasized. The India Meteorological Department developed and validates several crop pest forewarning models are given by table. 3.

Table 3: Various crop pests their congenial weather condition and regression model for forewarning of crop pest

Crop/ Pests	Station / Climatic zone	Period of damage	Stage of the crop	Congenial weather condition	Regression model
Cotton/ Jassid	**Akola/** Central vidarbha	End of July to mid-of Oct	Elongation /flowering/initial boll formation	After noon RH<72,SSH ≤ 4.4 hrs and $T_{min} \geq$ 22.4	Ic= -62.3 +7.35,Tmin(36th S.W) -1.5 RH1 (37th S.W)+0.62 RH2 (37th SW)
Thrips		July to Nov	Elongation /flowering/ initial boll formation	Tmean >= 26.8 ºC, Ssh >= 6.4 hrs., Rh2 <= 67%	I_C = -827.3- 23.7 Rh2 + 8.1 Ssh + 24.34 (33rd week)
Aphid		July to Jan	Elongation to boll formation	ssh <= 2 hrs. Tmean <= 250C (at early stage of crop) Tmin >= 15 0C Rh2 >= 54% ssh <= 5.1 hrs Rfl >= 1.3 mm	I_C = 0.18 + 0.44 Tmin- 18 Rh2 + 0.16 ssh + 29.9 Rfl (45th week)

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Pink Bollworm	**Parbhani** /Central Vidarbha	Oct to mid Dec	Flowering to boll formation	T_{min}> 20 ^{0}C , Rh_1> 60% Rfl > 0.5 mm, Clouding	I_C = -27.5 + 0.83 Tmin + 1.7 Ssh + 32.3 Rfl (42^{nd} week)
		Oct to mid Dec	Flowering to boll formation	Rh_1 > 60%, Tmean : 24-28^{0}C, Rfl > 0.5 mm Clouding	I_C = 8.8 - 0.18 Rh_2 + 0.3 Rfl (42^{nd} week)
American Bollworm	**Akola/** Central Vidarbha	August to Dec	Elongation to boll development	T_{min}< 11^{0}C Rh_2 < 18%	----
	Coimbatore/- ---	Sept to Nov	Flowering to picking	T_{mean}< 30^{0}C Rh_2< below normal	----
	Nagpur, Wardha,/ Eastern Vidarbha	Sept to Nov	Flowering to boll formation	Prolong dry condition T_{min}< 23 ^{0}C Rh_1 < 80% Rh_2 < 60%	----
	Ganganagar,/ Irrigated North Western plain	Sept to Nov	Flowering to Boll formation	Prolong dry condition Tmin <23ºC Rh_1 < 80% Rh_2 < 60%	----
Spotted Bollworm	**Surat (Gujarat) /--**	Oct to Dec	Boll formation	Ssh : 5-7 hrs.	---
				Rh1 : 95 - 100% Rfl (weekly total) : 170 - 210 mm (Last week ofAugust)	
Groundnut /Leaf Minor	**Akola/** Central Vidarbha	August September	Pod formation to Pod ripening	Tmax < 31 ºC Rh1 : 85% Ssh > 3 hrs. Occasional rain	
Pigeon pea/Heliothis Armigera	**Rahuri /** Central Maharashtra Plateau	(June to Nov) & (Nov to March)	Flowering to Pod formation	Tmin < 12ºC , Rh1 < 80 % Rh2 < 45% , Ssh > 6.6 hours	----
Tomato/ Early blight	**Pune** Central Maharashtra Plateau	Sept to Nov	-----	Tmax : 3ºC above normal	----
Potato /Potato Beetle		Any time when cultivated	----	Station annual rainfall :	

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				600-1500 mm Temp. range : -4 to + 38°C Favorable soil temp.	
Rice /Gall Midge	**Pattambi**	July	Vegetative	T_{max} > 28.9°C Ssh > 2.5 hrs	I_C=-521.9+18.63 T_{max}(30th S.W)-2.73 Ssh(30th S.W) [for 1st generation of pest at 32nd S.W(6-12August)]
Green Jassid	**Pattambi**	July	Vegetative	T_{min}< 22.1°C	IC=3853.6-76.3 T_{max}-120.4 T_{min}(30th S.W)+16.9 Rh_2-8.8 Ssh+0.5Rfl [for 1st generation of pest at 33rd S.W(13- 19 August]
		August	Flowering	T_{max}< 29.5 °C Rh_2 > 75.2 % Ssh < 4 hrs. Rf >	IC=1461.6-105.0 Tmax-124.4Rh_1-1.96 Rh_2+131.8 Ssh) [for 2nd genera

				86 mm	tion of pest at 37th S.W(10- 16 Sept]
		Sept	Grain formation	T_{max}> 31.2°C Rh_1<94% Rh_2<71% Ssh>5.3 hrs.	IC=4237.6-24.1 T_{max}-35.2 Rh_1-3.4 Rh_2+32.7 Ssh[for 3rd generation of pest at 37th S.W(24 - 30 September]
Stemborer	**Puri, Palghat ,Panagar, Kanpur**	June - Oct & Nov - April	Tillering to maturity	T_{mean}< 28°C Continuous rain	
	Bhubaneswar (Orissa)	Sept	Grain formation	T_{max}> 33°C	
		Nov	Early maturity	T_{min} : 17-18°C	
		Nov	Late maturity	Rh_1 : 80-85%	
		Feb	Elongation	Less rainfall & Evaporation > 4mm	IC=-195.8-3.0Rfl (5th S.W)+6.74Ep (6th S.W)+3.11 Rh^1 (12th S.W)-1.64 T^{min} (12th S.W)
		April	Flowering	T_{min}< 23°C Ssh>8 hrs.	
	Bhubaneswar (Orissa)	Feb	Elongation	Less rainfall & Evaporation >	IC=-195.8-3.0Rfl (5th S.W)+6.74Ep (6

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				4mm	thS.W)+3.11 Rh^1 (12th S.W)-1.64 T^{min} (12th S.W)
		April	Flowering	T_{min}< 23ºC Ssh>8 hrs.	
	Pattambi	Dec (previous year)	Non-crop season	Soil Temperature < 24ºC	IC=395.31-4.80St(51st.W)-6.50Tmax (14th S.W) IC=-61.0+3.834Ssh (30th S.W)+5.8T_{max} (31stS.W)-1.0Rh_2 (36th S.W)
		April	Non-crop season	T_{max}< 36 ºC	
		July	Vegetative	Ssh > 4 hrs. T_{max}> 28.8 ºC	
		Sept	Grain formation	Rh2 < 71%	
	Pattambi	Nov	Sowing	T_{max}< 31.9 ºC, Rh1< 94%, Rfl < 28.2 mm	
		Dec	Transplanting	Tmax < 32.8 ºC, Rh1 < 81%, Rh2 < 47%	

Source: India Meteorological Department (IMD)

Role of National Centre for Integrated Pest Management (NCIPM) for forewarning of crop pest outbreak under the impact of climate change scenario

National Centre for Integrated Pest Management plays an important role for forewarning of insect pest under the impact of climate change under the project entitled national initiative climate resilient agriculture (NICRA) and CROPSAP project. There are several prediction rules developed and validate for crop pest (NCIPM, news letter January to June 2012, Research Highlight.

Prediction of cotton sap feeders at Central India

Jassids: Weather based criteria viz., mean temperature of 25-28ºC, mean humidity of 65- 85%, total rainfall of 50-80 mm and rainy days between 2 and 4 days of any standard meteorological week predict the severity levels based on mean jassid population per three leaves were categorized as too high (>8), moderate (>4-8) and low (<4). All four, three and two or less of the formulated, weather criteria being satisfied predict high, moderate and low levels of jassid severity, respectively.

Mirids: Fulfilling e”5, four and d”3 of the six weather based criteria viz., maximum temperature

>310C, minimum temperature between 21 & 24ºC, relative humidity (morning) >85%, relative humidity evening between 30-70%, rainfall <25 mm and rainy days between 2 and 4 days on weekly basis predict the severity of mirids (*Campylomma livida* Reuter) on Bt cotton as to high (>4 nos/plant), moderate (>2-4 nos/ plant) and low (0-2 nos/ plant), respectively.

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Thrips: Mean temperature of 25-29ºC, mean humidity of 67-86%, total rainfall of 30-80 mm

and rainy days between 3 and 6 days of any standard meteorological week predict the levels of severity of thrips in conjunction with severity levels categorized based on mean thrips population per three leaves as to high (>10), moderate (>5-10) and low (<5). All four, three and two or less of the formulated four weather criteria being satisfied predict high, moderate and low levels of thrips, respectively.

Prediction of rice yellow stem borer: Location: Raipur (Chhattisgarh): Criteria: Weather based criteria viz., maximum temperature of 31-34ºC, minimum temperature between 22 & 23ºC relative humidity (morning) of 89-92%, rainfall 0-10 mm and sunshine hours of 6-9 hr/day predict the severity viz., High (>1000), Moderate (100-1000) and Low (<100) of yellow stem borer (YSB) based on light trap catches on weekly basis. Rule: More than three, three and less than three out of five weather parameters in the criteria predict high, moderate and low severity of YSB, respectively.

Location: Pattambi (Kerala): Criteria: Weather based criteria viz., maximum temperature of 31-34.5ºC, a minimum temperature of 20-21ºC, relative humidity (morning) of 85-95 %, relative humidity (evening) of 35- 50 %, no rainfall and sunshine hours >8.5 hrs/day predict the severity viz., High (>40), Moderate (20-40) and Low (<200) of yellow stem borer (YSB) based on light trap catches on a weekly basis. Rule: Satisfying all six, five and four or less, out of six weather based criteria predict high, moderate and low severity of YSB, respectively (Data sets used: 2000-2007).

Location: Aduthurai (Tamil Nadu): Criteria: Weather based criteria viz., maximum temperature of 30-32ºC, a minimum temperature of 20-22ºC, relative humidity (morning) of 90-93%, total rainfall <10 mm and sunshine hours >8- 9 hrs/day predict the severity viz., High (>200), Moderate (100-200) and Low (<100) of yellow stem borer (YSB) based on moth catches in light traps on a weekly basis. 8-9 hrs/day predict the severity viz., High (> 200), Moderate (100-200) and Low (<100) of yellow stem borer (YSB) based on moth catches in light traps on a weekly basis. Rule: Satisfying more than three, three and two or less, out of five weather based criteria predict high, moderate and low severity of YSB.

Prediction of rice pests at Raipur (Chhattisgarh): Gall midge: Criteria: Weather based criteria viz., maximum temperature of 32-34 ^{Oz}, minimum temperature of 19-22ºC, total rainfall of <10 mm, relative humidity (morning) of 89-93% and sunshine hours of 7- 9 hrs/day predict the severity viz., High (>200), Moderate (100-200) and Low (<100) of gall midge based on catches in light trap on a weekly basis. Rule: Satisfying all five, four and three or less, out of five weather based criteria predict high, moderate and low severity of gall midge, respectively.

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Combination of pests (YSB, Gallmidge, Green leaf hopper and Case worm): Criteria: Weather based criteria viz., maximum temperature of 31-34ºC, minimum temperature of 20-23ºC, total rainfall of <10 mm, relative humidity (morning) of 89-93% and sun shine hours of 8-9 hrs/day predict the severity viz., High (>1000), Moderate (500- 1000) and Low (<500) of YSB, Gall midge and Case worm, and High (>2000), Moderate (1000-2000) and Low (<1000) of GLH based on catches in light trap on weekly basis. Rule: Satisfying four or more, three, and two or less out of five weather based criteria predict high, moderate and low severity of all pests.

Prediction of *Spodoptera litura* on Groundnut at Dharwad (Karnataka): Criteria: Weather based criteria viz., maximum temperature of 25-28ºC, a minimum temperature of $>19.5^{Oz}$, relative humidity (morning) of >90%, relative humidity (evening) of 78-83% and rainfall <20 mm predict the severity based on weekly pheromone trap catches viz., High (>400), Moderate (200-400) and Low (<200) of *S. litura*. Rule: Satisfying all five, four and three or less, out of five weather based criteria predict high, moderate and low severity of *Spodoptera*.

Validation of a prediction rule of Helicoverpa armigera in pigeonpea at Gulbarga during 2001-2010 the prediction rule was developed at NCIPM earlier (Das *et al*., 2001)

Population level (yearly male moth catch/ light trap)

a) High (> 2000): A^-B^+ parameters satisfied

b) Moderate (1000-2000): A^-B^- or A+B+ parameters satisfied

c) Low (< 1000): A^+B^- parameters satisfied

1. Weather parameter

   a. A (Rainfall during the months of June – September)

   b. B (Rainfall during month of October)

   c. +/- Surplus / deficit rainfall

Year	Rainfall (mm) June – Sept.	Surplus / deficit Normal =580.5 mm	A	Rainfall (mm) Oct.	Surplus/ deficit Normal =81.8 mm	B	Predicted population level	Observed population	Observed population level
2001	527.3	-53.2	A-	56.4	-25.4	B-	(A-B-) Moderate	3218	Severe
2003	411	-169.5	A-	14.2	-67.6	B-	(A-B-) Moderate	1033	Moderate
2004	511.2	-69.3	A-	121.2	39.4	B+	(A-B+)Severe	1130	Moderate
2005	626.4	45.9	A+	67.5	-14.3	B-	(A+B- Low	793	Low
2006	338.3	-242.2	A-	37.4	-44.4	B-	(A-B-) Moderate	1062	Moderate
2007	710.6	130.1	A+	14.7	-67.1	B-	(A+B-) Low	751	Low
2008	486.4	-94.1	A-	74.4	-7.4	B+	(A-B+ Severe	1268	Moderate
2009	681.2	100.7	A+	180.1	98.3	B+	(A+B+) Moderate	773	Low
2010	746	165.5	A+	87.6	5.8	B-	(A+B- Low	122	Low

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The thumb rule developed earlier by (**Das *et al* (2001**) at NCIPM was validated with the weather and light trap catch (moth) data during 2001-10. Out of 10 years, the prediction was perfectly alright for 6 years. In other years, there was one level deviation. Except the year 2001-02, observed level was one scale lower than predicted one and the results were used without any harm.

Climate change and changing scenario of pathogens

Climate change may affect plant pathosystems at various levels viz. from genes to populations and from ecosystem to distributional ranges; from environmental conditions to host vigour to susceptibility; and from pathogen virulence to infection rates. Climate change is likely to have a profound effect on geographical distribution of host and pathogens, changes in the physiology of host-pathogen interactions, changes in the rate of development of the pathogens e.g., increased oversummering and overwintering of pathogens, increased transmission and dispersal of pathogens and the emergence of new diseases. Similarly, prolonged moisture may create a new scenario of potential diseases in SAT crops, such as anthracnose, collar rot, wet root rot, and stunt diseases in chickpea; to *Phytophthora blight*, *Alternaria blight* in pigeonpea, leaf spots and rusts in groundnut , blast and rust in pearl millet, leaf blight and grain mold complex in sorghum.

Efforts are underway across laboratories to forecast the changing scenarios of pathogens and diseases of SAT crops under variable climatic conditions through simulation modeling and targeted surveys. Studies are also being initiated to understand the behavior of the vectors of pathogens from the point of view epidemic development as well as Biosecurity **Pande *et. al* 2010.**

Climate change and crop disease

Climate factors that influence the growth, spread, and survival of crop diseases include temperature, precipitation, humidity, dew, radiation, wind speed, circulation patterns, and the occurrence of extreme events. Most analyses conclude that in a changing climate, pests may become even more active than they currently are, thus posing the threat of greater economic losses to farmers (**Coakley *et al.*, 1999**). Higher temperature, humidity and greater precipitation, on the other hand, are likely to result in the spread of plant diseases, as wet vegetation promotes the germination of spores and the proliferation of bacteria and fungi, besides influencing the life cycle of soil nematodes and other organisms.

Effect of elevated CO_2 on crop disease dynamics

1. Both enhancement and reduction in disease severity under elevated CO_2 has been reported. Elevated CO_2 would increase canopy size and density of plants, resulting in a greater biomass production and microclimates may become more conducive for rusts, mildews, leaf spots and blight development. Decomposition of plant litter is important for nutrient

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cycling and in the saprophytic survival of many pathogens. Because of high C: N ratio of litter as a consequence of plant growth under elevated CO_2, decomposition will be slower. Increased plant biomass, slower decomposition of litter, and higher winter temperature could increase pathogen survival on over-wintering crop residues and increase the amount of initial inoculation available for subsequent infection.

2. Some fungal pathosystems under elevated CO_2 revealed two important trends. First, delay in the initial establishment of the pathogen because of modifications in pathogen aggressiveness and/or host susceptibility. For example, reduction in the rate of primary penetration of *Eysiphe graminis* on barley and a lengthening of latent period in *Maravalia cryptostegiae* (rubervine rust) has been observed under elevated CO_2. Here, host resistance may have increased because of changes in host morphology, physiology, nutrients and water balance. A decrease in stomatal density increases resistance to pathogens that penetrate through stomata. Under elevated CO_2 barley plants were able to mobilize assimilates into defense structures, including the formation of papillae and accumulation of silicon at sites of appressorial penetration of *Erysiphe graminis*.

3. At elevated CO_2, increased partitioning of assimilates to roots occurs consistently in crops such as carrot, sugar beet, and radish. If more carbon is stored in the roots, losses from soil-borne diseases of root crops may be reduced under climate change. In contrast, for foliage diseases favored by high temperature and humidity, increases in temperature and precipitation under climate change may result in increased crop loss. The effects of enlarged plant canopies of elevated CO_2 could further increase crop losses from foliar pathogens.

4. The second important effect is an increase in the fecundity of pathogens under elevated CO_2. Following penetration, established colonies of *Erysiphe graminis* grew faster and sporulation per unit area of infected tissue was increased several-fold under elevated CO_2. It has been also observed that under elevated CO_2 out of the 10 biotrophic pathogens studied, disease severity was enhanced in six and reduced in four and out of 15 necrotrophic pathogens, disease severity increased in nine, reduced in four and remained unchanged in the other two.

A preliminary study also showed that hot and comparatively dry conditions were favorable for rice-hispa incidences while a decrease in minimum temperature under humid and cloudy condition caused the incidences of rice blast. Working with tikka disease infestation of groundnut, it is observed that decrease in maximum and minimum temperature below 32ºC and 19ºC respectively, and increase in the morning and afternoon relative humidity above 90% and 80% respectively favoured the infestation of tikka disease of groundnut. Similarly increase in maximum temperature was found to increase the infestation of both fruit canker of guava and early blight of tomato. Decrease in afternoon relative humidity favored the infestation of fruit canker of guava and rust of fig. Fall of minimum temperature and rise in bright hours of sunshine also aggravated the incidence of fruit canker of guava and rust.

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Table 4Effect of increased CO_2 concentrations of pathogens

Author	**Study**	**Effect**
Hibberd *et al.* (1996)	The effect of elevated concentrations of CO_2 on the infection of barley by *Erysiphe graminis* was determined.	The percentage of conidia that progressed to produce colonies was lower in plants grown in 700 than in 350 ppm CO_2.
Tiedemann and Firstching (2000).	Interactive effects of elevated CO_2 and O_3 levels on wheat leaves infected with leaf rust fungus *Puccinia triticina* were described.	Elevated CO_2 increased the photosynthetic rates of the diseased plants by 20 and 42% at the ambient and elevated ozone concentrations, respectively.
Jwa and Walling (2001).	The effects of elevated CO_2 concentrations on the development of *Phytophthora parasitica* (root rot) in tomato were evaluated.	The extra CO_2 completely counterbalanced the negative effect of the pathogenic infection on overall plant productivity.
Chakraborty *et al.* (2002).	The germination rates of conidia of *C. gloeosporioides* were determined.	Spore germination was reduced and extended incubation period was at 700 ppm, and Anthracnose severity was reduced.
Karnosky *et al.* (2002).	Elevated CO_2 and tropospheric O_3 concentrations were related to infection by rust (*Melampsora medusae* f. sp tremuloidae) in aspen (Populus tremuloides Michx.)	Three- to five-fold increases in levels of rust infection index were found.
Pangga *et al.* (2004).	The relative importance of canopy size and induced resistance to Colletotrichum gloeosporioides was examined at atmospheric CO_2 concentrations of 350 and 700 ppm. Susceptible Stylosanthes scabra (Fitzroy) were evaluated in a controlled environment facility (CEF) and the field.	Up to twice as many lesions per plant were produced in the high CO_2 plants, because the enlarged canopy trapped many more pathogen spores.
Kobayashi *et al.* (2006).	Pyricularia oryzae Cavara and Rhizoctonia solani Kühn were evaluated.	Rice plants grown in an elevated CO_2 concentration were more susceptible to leaf blast than those in ambient CO_2.
Eastburn *et al.* (2010).	The effects of carbon dioxide (CO_2) and ozone (O_3) on three soybean diseases (downy mildew, Septoria and sudden death syndrome) were determined in the field.	Changes in atmospheric composition altered disease expression. Elevated CO_2 reduced downy mildew disease severity. But increased brown spot severity and without effect in sudden death syndrome.
Strengbom and Reich (2006).	The incidence of leaf spot on mature leaves of Solidago rigida was assessed. The incidence of disease was reduced by half under ECO_2 concentrations.	Disease incidence was lower in plots with either elevated [CO_2] or enriched N (-57 and -37%, respectively) than in plots with ambient conditions.
Matros *et al.* (2006).	The response of tobacco to potato virus Y was evaluated.	The titre of viral coat-protein was markedly reduced in leaves under these conditions at both nitrogen levels. The accumulation of phenylpropanoids, may result in an earlier confinement of the virus at high CO_2.
Lake and Wade (2009).	Interactions between Erysiphe cichoracearum and Arabidopsis thaliana under elevated levels of CO2 were assessed.	The number of established colonies (networks of mycelia) on mature leaves increased significantly

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Runion *et al.* (2010).	The effects of elevated atmospheric CO_2concentrations on two southern forest diseases (Cronartium quercuum and Fusarium circinatum) were assessed.	In general, disease incidence was decreased by exposure to elevated CO_2, and increased the latent period (time to sporulation) for fusiform rust on red oak seedlings.
Shin and Yun (2010)	The effects of elevated levels of CO_2 and temperature on the Incidence of four major chili pepper diseases (Anthracnose (*Colletotrichum acutatum*), Phytophthora blight (*Phytophthora capsici*)) and two bacterial diseases (bacterial wilt (*Ralstonia solanacearum*) and bacterial spot (*Xanthomonas campestris* pv. vesicatoria)) were determined.	Elevated CO_2 and temperature significantly increased the incidence of two bacterial diseases. Anthracnose decreased and Phytophthora blight slightly increased.
McElrone *et al.* (2010)	Effect of elevated CO_2 and inter annual climatic variability affect Cercospora leaf spot diseases of two deciduous trees	When significant changes did occur, disease incidence and severity always increased under elevated CO_2.

Role of Indian metrological department for forewarning of crop disease intensities

Crop/ Disease	Station	Period of damage	Stage of the crop	Congenial weather condition
Rice/ Blast	Maharashtra and Karnataka	August to January	Tillering to Maturity	T_{min} < 23.5°C Rh_1 > 90% Rh_2 > 80% Partly clouding
Groundnut / Tikka	Warangal Hyderabad Nagpur Anand			
Rust	Akola (Maharashtra) /Central Vidarbha	September & October	Pod ripening	Tmin < 16.30C Rh1 :20-40% Rh2 :50-95% Ssh > 7.5 hrs.
Tikka	Warangal Hyderabad Nagpur Anand	*Kharif Rabi*	Pod formation to maturity	Tmax<30^0 C Rh_1 > 80 % Rh_2 > 60% Clouding condition
	Ahmedabad Anand Bhavnagar Jamnagar Junagarh Veraval (Gujrat)	--	Pod formation to Pod development	Tmax < 34 ^{0}C Tmin < 22 ^{0}C Rh_1 > 82% Rh_2 > 78% Clouding
	Akola (Maharashtra) /Central Vidarbh	July to October (mere in October)	----	**i)** Low range of day –night temperature **ii)** Less sunshine hours **iii)** Increase in rainfall (July) **iv)** Fall in Tmean in 1st fortnight of August

Sources: India Meteorological Department (IMD)

Other sources for forewarning of crop pest

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Table 3 Weather parameters related to *Phytophthora infestans*

Source	Temperature condition	Humidity condition
(Beaumont, 1947)	>10°C	>75%
(Smith, 1956)	>10°C	>90% for >11 hours
(Hyre, 1954)	>7.2°C – <25.5°C for last five days	Total rainfall >3cm for last 10 days
(Duniway, 1983)	>3°C - <26°C, longer than 8 hours	100% relative humidity for 8 hours

Table 4 Weather parameters related to *Fusarium* head blight graminearum

Source	Temperature condition	Humidity condition
(Pugh *et al.*, 1933)	25°C	Continuous wetness for 48 hours relates to 77% infection
(Cook and Christen, 1976)	20°C - 30°C	Substrate is moist
(Lacey *et al.*, 1999)	>9°C - <26°C	

Favorable condition for crop disease in **rice crop**

Crop diseases	Favorable condition
Rice blast	Application of excessive doses of nitrogenous fertilizers, intermittent drizzles, cloudy weather, high relative humidity (93-99 per cent), low night temperature (between 15-20°C), more number of rainy days, longer duration of dew, cloudy weather, slow wind movement and availability of collateral hosts.
Brown spot	Temperature of 25-30°C with relative humidity above 80 per cent is highly favorable. Excess of nitrogen aggravates the disease incidence.
Sheath rot	Closer planting, high doses of nitrogen, high humidity and temperature around 25-30°C. Injuries made by leaf folder, brown plant hopper and mites increase infection
Sheath blight	High relative humidity (96-97 per cent), high temperature (30-32°C), closer planting and heavy doses of nitrogenous fertilizers
False smut	Rainfall and cloudy weather during the flowering and maturity periods are favorable.
Bacterial leaf blight	Clipping of tip of the seedling at the time of transplanting, heavy rain, heavy dew, flooding, deep irrigation water, severe wind, and temperature of 25-30 °C and application of excessive nitrogen, especially late top dressing

Sources P. Raja and R. Saravanan integrated diseases management in paddy, college of horticulture and forestry, central agricultural university, Pasighat East Siang district, Arunachal Pradesh.

Relationship between diseases and weather condition in groundnut

Several diseases causing large losses in both yield and quality of seeds affect the agricultural crop. Weather indirectly influences the yield and quality through its effects on the occurrence and development of diseases. **Kolte (1985)** reviewed diseases of groundnut in relation to weather conditions. Early and late leaf spots

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(*Cercospora arachidicola* and *Puccinia personate*) are considered the most important diseases of groundnut. They have been reported throughout the groundnut-growing areas of the world. Leaf spots cause huge yield loss in groundnut due to severe defoliation. Weather conditions conducive to the occurrence of early and late leaf spots as reported by different researchers are summarized in Table 10.2.6, which basically conveys that rainfall, leaf wetness and temperature are the most important factors for the occurrence and epidemiology of leaf spots.

Disease	Favorable weather condition	References
Rust	In India, a continuous dry period characterized by high temperature (>26°C) and low relative humidity (<70 per cent) is reported to delay rust occurrence and severity, whereas intermittent rain, high relative humidity and 20°C to 26°C temperature	(Siddaramaiah *et al.*, 1980)
	In the Parbhani region of Maharashtra, India, observed that if average temperature of 20°C–22°C, relative humidity above 85 per cent and three rainy days in a week prevail for two weeks, an outbreak of rust is likely.	Mayee (1987)
	rainfall of about 200 mm, temperature between 23.5°C and 29.4°C, and relative humidity in the range of 67 to 84 per cent	Lokhande *et al.* (1998)
Sclerotinia Blight	Optimum temperature 20°C and 25°C	(Dow *et al.*, 1988).
Collar rot	High soil and air temperatures	(Kolte, 1985).
	Temperature 31°C to 35°C	(Chohan, 1969).

Conclusion:

Every year crops are being damaged by pests and diseases. Due to lack of proper operational forecasting system for the incidences of pests and diseases, it becomes difficult to adopt a plant protection measures at the right time. Weather based pest and disease forewarning provides opportunity to farmers for preparedness and for taking timely action to apply bioagents and pesticides which ultimately cut down the cost of production. On the basis of current review paper, we have concluded forewarning crop pest and disease outbreak and intensities is an important technique under the climate change scenario. In this study, we find out the congenial weather for the outbreak and intensities of crop pest and disease which is helpful for a reduction of chemical use and increases the crop yield. Some scientist who suggests the harmful effect of climate change in future, such as migration of pest and disease in northward, increase the number of generation and plant become more susceptible to crop pest and disease which can help long term future planning for crop pest and disease management.

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