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IMPACT OF CLIMATE CHANGE VARIABLES ON CROP PESTS AND MITIGATION STRATEGIES : A REVIEW

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Abstract

Climate change is one of the most important environment problems affecting every country worldwide. Climate change favours conditions for plant pests in new areas as well as changing the way they are transmitted. Climate induced changes in pest activity affect agricultural production and food safety in several ways. Changes in climate variables may favour wider geographical distribution, prolonged overwintering, altered population growth rates, increased number of generations, extension of the development season, changes in crop-pest synchrony, inter-specific interactions and abundance of natural enemies, species extinction, increased risk of invasive pests and altered efficacy of crop protection technologies. Climate warming will also weaken crop health; reduce the host plant resistance, effectiveness of transgenic plants, natural enemies, efficacy of biopesticides and synthetic chemicals in pest management. Therefore, there is a need to generate information on the likely effects of climate change on crop pests to develop suitable technologies that will be effective in future to mitigate the adverse effects of climate change on food security. This paper attempts to enlighten some of the documented views on the impact of climate warming in agriculture vis-à-vis their repercussions on the incidence of crop pests, specifically on the effects of raising temperatures, elevated CO_2 levels, precipitation changes and the existing pest management practices in agro-ecosystems.

Key words: Climate change, crop plants, pests, pathogens, mitigation strategies.

Introduction

Climate change resultant global warming has become issue of serious concern worldwide for existence of life on the earth (IPCC, 2007). Since past hundred years, the atmospheric temperature has increased by 0.8°C and is expected to reach 1.1-5.4°C by the end of next century (Aggarwal, 2008). On the other hand, CO_2 concentration in the atmosphere has increased drastically from 280ppm to 370ppm and is likely to be doubled in 2100 (IPCC, 2007). This change is attributed mainly to the over exploitation of natural resources for various developmental activities such as increased urbanization and industrialization resulting in aberrant weather events like changes in rainfall patterns, frequent droughts and floods, increased intensity and frequency of heat and cold waves, outbreaks of pests and diseases, affecting many biological systems and ultimately the human beings (IPCC, 2007). Agro-ecosystem environment is largely influenced by interactions between abiotic and biotic components. Crop plants grow in agro-ecosystem environments are attacked by a wide range of pest-insects, mites, nematodes and pathogens such as viruses, bacteria, fungi and mycoplasma like organisms. The abiotic stress factors (temperature, humidity, rainfall, soil factors, pollutants etc.) modulate the effects of biotic stresses (weeds, insect-pests, pathogens, nematodes etc.) (Awmack *et al.*, 1997) and are most harmful when occur in combination, greatly influencing crop growth and productivity.

Globally, pests are estimated to destroy about one third of our crops (Dhaliwal and Dilawari, 1993; Oerke *et al.*, 1994) and are an increasingly serious constraint to crop production, in spite of the advances in pest control technology over the last half century (Parvatha Reddy, 2013). Climate warming as predicted would further increase pressure from pests and diseases. Increased temperatures and longer growing seasons would result in upsurge of pest population in temperate regions of Asia (Aggarwal, 2008). In general, most pest species are favoured with warm and humid weather. In cropped

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ecosystem, pest outbreaks often coincide with changes in climatic conditions, such as early or late rains, drought, or increases in humidity, flood and cyclonic storm (IPCC, 2007). These climatic variables coupled with pest occurrence will affect the crop growth, yield potential, availability of food grains and threaten food security (Tilman *et al.,* 2001), besides depressing rural livelihoods. This paper briefly enlighten the impact of climate warming in agriculture vis-à-vis their repercussions on the incidence of crop pests, with reference to the effects of raising temperatures, elevated CO_2 levels, precipitation changes and the existing pest management practices in agro-ecosystems.

Climate and Weather Change

The terms 'weather and climate' are frequently considered to be interchangeable, but weather and climate refer to different things. Weather is brief, rapidly changing condition of the atmosphere at given place and time, influenced by movement of air masses. Climate, on the other hand, should more accurately be the applied to the average weather conditions over a long period of years (Parvatha Reddy, 2013). The term "climate change" is used to describe a gradual increase in the average temperature of the earth's atmosphere and its oceans, a change that is believed to be changing the earth's climate forever (Cammell and Knight, 1991). Curiously, climate change is the long term changes in the statistical distribution of weather pattern over a period of time, ranging from months to millions of years (Porter *et al.,* 1991; Lal, 2003). Climate change may be limited to a specific region, or may occur every country across the world.

Impact of Climate Change in Indian Agriculture

India, being a tropical country, is more challenged with impacts of looming climate change. The Indian climate has undergone significant changes showing increasing trends in annual temperature with an average of 0.56°C rise over last 100 years (IPCC, 2007). Climate warming was more pronounced during post monsoon and winter season with increase in number of hotter days in a year (Chahal *et al.,* 2008). Already, the productivity of agriculture is limited by its high dependency on monsoon rainfall which is most often erratic and inadequate in its distribution (Aggarwal, 2008). The country is experiencing declining trend of agricultural productivity due to fluctuating or increased temperatures, elevated CO_2, erratic rainfall, frequently occurring droughts and floods, submergence, soil salinity problem and increased outbreaks of pests and diseases (IRRI News, 2009; Karuppaiah and Sujayand, 2012). According to Litchfield, (2010), the overall impact of climate change on agricultural production will be negative. Climate changes resulting of temperature extremes, drought and salinity intrusion have already affected crop production with declining crop yields in many parts of the world. Increases in water stress have also affected the production of major crops, particularly rice, which needs significant amounts of water (Kiritani, 2006). The diagram below depicts the raise in population growth and price of food in the future as climate change occurs. Climate change will also lead to shorter growing seasons and less arable land**,** both of which will diminish the total amount of agriculture and the total food supply with increasing the food demand. These factors together will attribute to a rise in the market price of food, leading to conflict over food security (Fig. 1).

Researchers have predicted that by the end of next century (2100), the temperature in India is likely to increase by 1-5°C (Lal, 2003; FAO, 2008). A report by NATCOM, (2004) indicated that there will be 15-40% increase in rainfall with high degree of variation in its distribution. Besides, the country is likely to experience frequently occurring extreme events like heat and cold waves, heavy tropical cyclones, frosts, droughts and floods (IPCC, 2007). The climate change lead changes in crop pest status will perilously affect agricultural production and the livelihood of farmers in the country where larger portion of work force is directly dependent on climate sensitive sectors such as agriculture (Chahal *et al.,* 2008; Gupta, 2011). It has been reported that global climate warming may lead to altitude wise expansion of the geographic range of crop pests (Harrington *et al.,* 2001). Thus, with changing climate warming it is expected that the growers of crops have to face new and intense pest problems in the years to come. Furthermore, these problems are likely to put forth major challenge to attain a goal of food security.

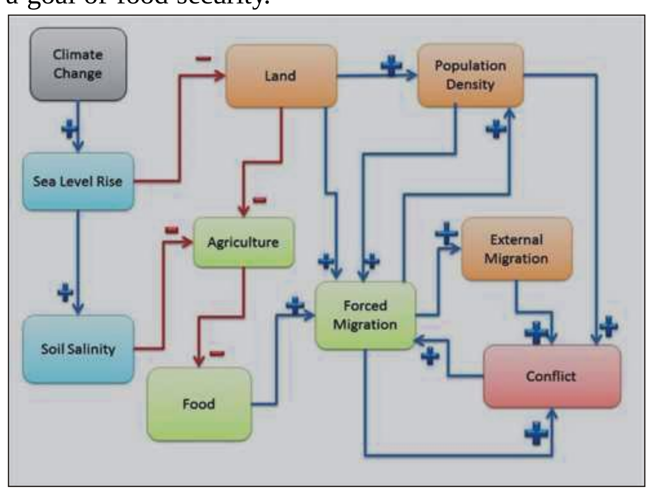

Fig. 1: Effect of climate change events lead to forced migration of people resulting in conflict over food security (Source: Adapted from W.A. Litchfield, 2010).

Table 1: Reports on empirical studies on crop-pests interactions in the context of climate change.

	Climatic factor studied	Impact on host plant	Impact on pests
(a)	High temperature, Drought/ water stress including precipitation changes	• Breakdown of resistance against target insect pests • Enhanced susceptibility of the crops to pest attack • Heavy loss in yield due to increased pest damage • Negative impacts on transgenic crops with reduced *Bt* toxin production	• More feeding by insects than the normal • Increased length of life stages • Potential for pest outbreaks • Prolonged development
(b)	Increased CO_2 levels	• Reduced nitrogen content of the plant tissue due to widening of Carbon: Nitrogen (C: N) ratio • Decrease in nitrogen-based plant defenses like alkaloids • Increase in carbon-based defenses such as tannins • Less stomatal openingIncreased water use efficiency • Reduced water loss through stomata • Extension of plant life span • Longer periods of habitat suitability for insects	• Enhanced feeding by insects in order to obtain sufficient nitrogen for their metabolism • Increased length of life stages • More foliage feeding than the normal • Ease in nutrient assimilation and digestion especially the nitrogen
(c)	Temperature × CO_2 combination (Ambient and elevated)	• Reduced leaf water content Increased concentration of soluble sugars • Declined nutritional quality of foliage	• Reduced larval weight gainIncreased larval feeding • Prolonged development
	Source: Adapted from Fand *et al.*, 2012 and Parvatha Reddy, (2013)		

Impacts on Insect and Mite Pests of Agriculture

In agro-ecosystem, pest habitat and survival strategies are strongly dependent on patterns of climate. Arthropod pests being poikilothermic nature, temperature is probably the single most important environmental factor influencing their behaviour, distribution, development, survival and reproduction (Bale and Hayward, 2010). The climate warming is aggravating pest problems with intensified yield losses, besides it hinders the extent of entomophilies pollination by disrupting the synchrony between plant-pollinator life cycles, with an estimated risk of reduction in world food production by one-third (Abrol, 2009; Fand *et al.*, 2012). With changing climate, it is expected that the growers of crops have to face new pest problems in the years to come. The major predictions about impacts of climate change on arthropod-pests are enumerated below:

- Loss of ecological biodiversity of pests
- Expansion of geographic ranges
- Increased overwintering survival
- Increase in number of generations
- Risk of introducing invasive alien species
- Impact on pest population dynamics and outbreaks
- Impact on crop-pest interactions
- Breakdown of host plant resistance
- Increased incidence of insect vectored plant diseases
- Reduced effectiveness of biological control agents
- Disruption of plant-pollinator interactions

Nearly 6.83% of world insect species are inhabitant in India (Alfred, 1998). The climate change may affect the relative abundance of different insect species and the species unable to adapt the changes may be lost in the due course of time (Thomas *et al.*, 2004). The negative effects of climate change are accelerating the rate of biodiversity loss, worldwide. Prior reports on empirical studies on crop-pests interactions in the context of climate change are enlisted in table 1.

Raising Temperature

Rising temperatures will also lengthen the breeding season and increase the reproductive rate of mealy bugs and thrips. Studies on aphids and moths have shown that increasing temperatures can allow insects to reach their minimum flight temperature sooner, aiding in increased dispersal capabilities (Awmack *et al.*, 1997; Andrew and Hughes, 2005). Increased temperatures could result in more insect species attacking more hosts in temperate climates (Bale and Hayward, 2010). Researchers have predicted that the higher temperatures in future may increase the damage on crops, by increasing the number of generations of the pest (Georghiou and Taylor, 1986; Yadav *et al.*, 2010).

Elevated CO_2 levels

Rise in CO_2 levels has role to hasten the canopy size and density of plants, resulting in a greater biomass production and microclimates that prevail amidst the crop canopy may more conducive for foliar pests (Cammell and Knight, 1991). Increased atmospheric CO_2 is expected to alter the nutritional makeup of crops, thereby favouring for severity of attack by insect pests (Brooks and Whittaker, 1999). A study on the two-spotted spider mites (*Tetranychus urticae*) raised on common beans grown at 600 and 700ppm CO_2 indicated that a significant decrease in the number of the offspring in the first and second generations (34% and 49%) respectively, compared to ambient CO_2 (Joutei *et al*., 2000). A similar experimentwas conducted, where *T. urticae* were raised on clover (*Trifolium repens*) grown at different CO_2 levels (395-748 ppm). The results showed a quite opposite effect: under elevated CO_2 spider mite reproduction increased significantly compared to lower CO_2 (Heagle *et al*., 2002).

Precipitation changes

Precipitation, whether optimal, excessive, or insufficient is a key variable that affects crop-pest interactions. Abnormally cool, wet conditions resulting of precipitation can also bring on severe insect infestations, although excessive soil moisture may drown out soil-residing insects (Mattson and Haack, 1987). Some sucking insects such as mealy bugs, aphids and thrips are very sensitive to precipitation and are killed or removed from crops by heavy rains. In inundated flood situations, positive relationship with outbreaks of rice armyworm, *Mythimna separata* (Walker) and *Spodoptera mauritia* (Boisd.), have been witnessed in rice fields, following excessive rainfall. Intense precipitation also tends to negatively impact insect populations in fields by decimating them by inducing pathogenic infections in different bio-stages of insects in diverse agro-ecosystem. For example, with the onset of post-monsoon, insect pathogenic fungi such as *Pandora delphacis* (Hori.) Humber, caused mycosis on population of rice brown planthopper (BPH) (*Nilaparvata lugens* Stal) (Ambethgar, 2002); similarly, *Zoophthora radicans* (Brefeld) Batko and *Beauveria bassiana* (Bals.) Vuill induced infections on field populations of rice leaf-folder (*Cnaphalocrocis medinalis* Guenee) in different periods (Ambethgar, 2002). All these epizootics were favoured by prevalence of high humidity following seasonal rainfall. The progression of mycoses declined towards drier periods. Considerations of these ecological factors are important when choosing any pest management options.

Impacts on Plant Disease Epidemics

The classic disease triangle recognizes the role of climate in plant diseases as no virulent pathogen can induce disease on a highly susceptible host if climatic conditions are not favourable. Climate influences all stages of host and pathogen life cycles as well as development of disease. A plant disease is any disturbance to the normal physiology of the plant brought about by an agent so that the affected plant changes in appearance and/or is less productive than a normal healthy plant of the same variety (Chakraborty *et al.*, 2000). However, the severity of plant disease over a period can fluctuate according to climatic variation as illustrated in fig. 2.

Climate variables that influence the growth, spread and survival of crop diseases include temperature, precipitation, humidity, dew, radiation, wind speed, circulation patterns (Sharma *et al.*,2010). Higher temperature and humidity and greater precipitation result in the spread of plant diseases, as wet vegetation promotes the germination of spores and the proliferation of fungi and bacteria and influences their life cycle. Fungal and bacterial pathogens are also likely to increase in severity in areas where precipitation increases (Parvatha Reddy, 2013). Under warmer and more humid conditions cereals would be more prone to diseases such as *Septoria*. In addition, increases in population levels of disease vectors could lead to increased epidemics of the diseases they carry.

Elevated temperatures

In general, temperature changes in any location had significant effects on disease development, although variation exists between different agro-ecological zones. Change in temperature will directly influence infection, reproduction, dispersal and survival between seasons and other critical stages in the life cycle of a pathogen. Elevation of ambient temperature and higher relative humidity resulted in greater risk of rice blast (*Pyricularia oryzae*) epidemics. Predictive models for potato and tomato late blight incited by *Phytophthora infestans* showed that the fungus infects and reproduces most

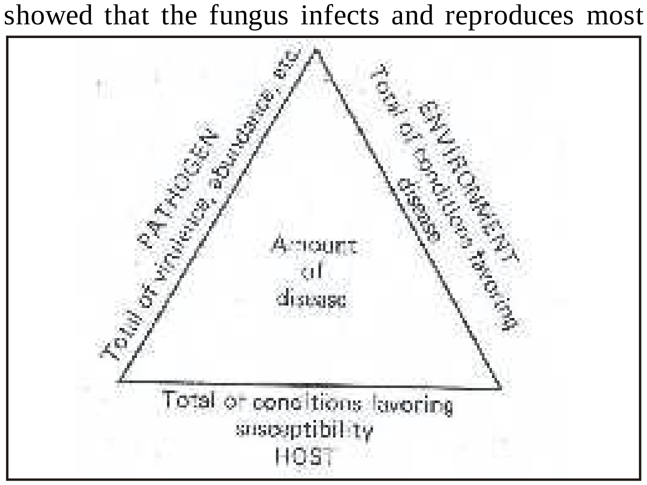

Fig. 2: The disease triangle showing interaction with host-pathogen and environment.

success fully during periods of high moisture that occur when temperatures are between 7.2°C and 26.8°C (Wallin *et al.*, 1950). Milder winter reported to be increase aphid development and their reproductive rates and lead to severe incidence of aphids-borne plant viral diseases in several crops. Systemic fungicides negatively influenced the physiological changes that slow uptake rates, such as smaller stomatal opening or thicker epicuticular waxes in crop plants grown under higher temperatures.

Elevated CO_2 levels

Elevated CO_2 would increase canopy size and density of plants, resulting in a greater biomass production and microclimates may become more conducive for foliar pathogens (rusts, mildews, leaf spots and blights) development. Increased plant biomass, slower decomposition of litter and higher winter temperature could increase pathogen survival on overwintering crop residues and increase the amount of initial inoculum available for subsequent infection. In soybeans, elevated CO_2 alone or in combination with ozone (O_3) significantly reduced downy mildew (*Peronospora manshurica*) disease severity by 39.66 percent. In contrast, elevated CO_2 alone or in combination with O_3 significantly aggravated the severity of brown spot disease caused by *Septoria glycines* (Eastburn *et al.*, 2009).

Precipitation patterns

Plant pathogens inciting apple scab, late blight and several root diseases are more likely to infect plants with increased moisture forecast models based on leaf wetness, relative humidity and precipitation measurements. In contrast, pathogens causing powdery mildew disease tend to thrive in conditions with lower moisture. Precipitation aided spread of bacterial pathogens to their host plants mainly by water, usually in the form of rain splash and insects. In humid and wet conditions, bacterial infections exuded bacterial propagules from plant tissues and spread in masses from host to host by rain splash and insects. Fungicide application following precipitation may improve its distribution (Schepers, 1996) but excessive or intense rainfall can deplete fungicide residue on the foliage. The more frequent rainfall may attract frequent application of fungicide for effective management of plant diseases.

Impacts on Plant Parasitic Nematodes

Plant parasitic nematodes are one of the important biotic constraints in crop production. Global warming resulting in elevated carbon dioxide (CO_2) and temperature in the atmosphere may influence plant pathogenic nematodes directly by interfering with their developmental rate and survival strategies and indirectly by altering host plant physiology. Severe droughts resulting in a reduction of soil water will most likely negatively affect soil nematodes.

Increased temperatures

Temperature is the most important factor influencing the biology of nematodes. Nematode developmental rate is directly influenced by the temperature with slower development at cooler and faster growth rate at warmer soil temperatures. Therefore, increase in atmospheric temperature due to global warming is expected to result in more number of generations per season and expansion of their geographical distribution range. Drier temperatures are expected to increase symptoms of water stress in plants infected with nematodes such as the soybean cyst nematode (Sticht *et al.*, 2009). Overwintering of nematodes is not expected to be significantly affected by changes in climate, although for some, such as the soybean cyst nematode, egg viability may be reduced in mild winters.

Elevated CO_2 levels

Plant parasitic 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. The number of herbivore, bacterivore and fungivore nematodes was significantly higher under winter wheat and sugar beets grown under elevated CO_2 (550 ppm), while the number of carnivore was not changed. The total numbers of herbivore, bacterivore and fungivore nematodes were higher under elevated CO_2 wheat than under elevated CO_2 sugar beet, most likely due to the very different root system of both plant species (Sticht *et al.*, 2009).

Impacts on Pest Management Strategies

Climate change resulting in raising temperature, elevated emission of greenhouse gases, severe droughts, is posing a serious challenge to sustainability of pest management practices by interfering with biotic and abiotic components and their interactions lead to the various impairment and consequences in pest management system as listed below.

- Breakdown of host plant resistance
- Reduced level of toxin proteins in transgenic crops
- Decline in the activity of natural enemies
- Reduced efficacy of biopesticides and synthetic pesticides
- Resurgence of pest organisms
- Resistance development in pest organisms
- Increased cost involvement for plant protection measures

- Interfering with food security and livelihood of farmers

Adaptation, Mitigation and Challenges Ahead

Adaptation refers to an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects that moderate, harm or exploit beneficial opportunities (Parvatha Reddy, 2013). In this context, the researchers indicated that climate change mitigation encompasses the actions being taken and those that have been proposed, meeting the challenges to limit the magnitude and/or rate of long-term global warming induced climate change. Keeping these aspects in view, the following aspects should be given weight age to mitigate the climate warming in agro-ecosystem

- Pest monitoring helps to prevent the spread of pests and diseases
- Breeding climate-resilient crop genotypes /varieties
- Rescheduling of crop calendars
- Adoption of organic farming and IPM to mitigate pest related stress
- Application of natural mulches to suppress harmful pests and diseases
- Crop rotations to interrupt specific relationships between pests and crop plants
- Soil and plant health management for suppression of pests and diseases
- Judicious/need based use of chemical inputs to reduce the severity of pests
- Screening of pesticides with novel mode of actions
- Wider adoption of Integrated Pest management (IPM) practices

Conclusion

Climate change will have serious consequences on diversity, distribution, abundance and phenology of pants, pests and pathogens. In India, pest damage varies in different agro-climatic regions across the country mainly due to differential impacts of abiotic factors such as temperature, humidity and rainfall. The extent of loss due to pests will impact both crop production and food security. Prediction of changes in geographical distribution and population dynamics of pests will be useful to adopt the pest management strategies to mitigate the adverse effects of climate change on crop production. Climate changes may also upsurge outbreaks of pests more frequently, particularly during extended periods of drought, followed by differential impacts of abiotic factors such as altered temperature, humidity and rainfall. The pest management components such as plant defense traits, host plant resistance, expression of *Bt* toxins in transgenic crops, natural enemies, biopesticides and synthetic pesticides will be rendered less effective as a result of climate warming. Considering serious consequences of climate change on diversity and abundance of insect-pests and the extent of crop losses, food security for 21st century is the major challenge for human kind in years to come. India, being a tropical country, is more challenged with impacts of looming climate change on devising crop protection and mitigation strategies for future pest management programme. The best economic strategy for farmers to follow is to use integrated pest management (IPM) practices to closely monitor pest and disease occurrence. In this context, there is a need to have a concerted look at the likely effects of climate change on crop health and devise appropriate measures to mitigate the effects of climate change on food security.

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