Technical Research Studies on

"Impacts of Climate Change on Agriculture and Food Security"

i. **Assessment of Climate Change Impacts on insect-pest proliferation in cotton-based cropping systems of Pakistan**

In Collaboration with

Pakistan Agricultural Research Council (PARC)

Global Change Impact Studies Centre (GCISC)

Ministry of Climate Change

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Abstract:

Global warming and climate change virtually affect all the possible changes in insects in one way or other. Pest number will undoubtedly continue to fluctuate from season to season, depending on the particular combination of weather conditions that occur each year. Predicting the impact of climate change on insects is a very complex exercise and a one that involves a great deal of modeling. Changes in geographical range and insect abundance will increase the extent of crop losses and, thus, will have a major bearing on crop production and food security. Distribution of insect pests will also be influenced by the changes in cropping patterns triggered by climate change. They have responded to warming in all the predicted ways, from changes in phenology and distribution, to undergoing evolutionary changes albeit at the population level. Climate change will also result in increased problems with insect-transmitted diseases. These changes will have major implications for crop protection and food security, particularly in developing countries where the need to increase and sustain food. The precise impacts of climate change on insects is somewhat uncertain because some climate changes may favors insects while others may inhibit a few insects.

Introduction:

Pakistan's economy is mainly based on agriculture sector. The major agricultural crops include cotton, wheat, rice, sugarcane, fruits and vegetables. Climate change is expected to adversely affect agricultural production, food security and rural livelihoods in South Asia (IPCC, 2014). Climate models suggest temperature increases between 0.5 and 2 ºC by 2030 and between 1 and 7 ºC by 2070 in the Asian Pacific region (Hii et al., 2009; Leal Filho, 2015). Particularly, temperatures are expected to increase more rapidly in arid zones of Pakistan, India and western China (Leal Filho, 2015). Studies suggest significant losses (4-10%) in cereal yields by 2100 in South Asian countries due to an increase in temperatures (Lal, 2011). Similarly, the uncertain and uneven rainfall distribution along with risks of floods and droughts are likely to undermine the agricultural growth in most of the South Asian countries. Pakistan is expected to experience losses in productivity of main staple crops, such as wheat and rice (IPCC, 2014b).

South Asian countries including Pakistan are particularly vulnerable to climate change due to limited lower adaptive capacity and more severe resource scarcity (Schilling et al., 2013). Climate change adds to the development challenges of the countries in the region that are still struggling with food insecurity and poverty issues. These impacts are very important for countries such as Pakistan, where agriculture employs 44% of the total labour force and provides livelihood to more than half of the population (Abid et al., 2016b). The majority of the population in Pakistan lives in rural areas and is characterized by poor and resource constrained small farming households.

A study of the potential vulnerability of crops to heat stress under a climate change scenario of a rise in temperature of 0.3º C per decade shows that all crops suffer heat stress, but crops like wheat, cotton, mango and sugarcane are more severely affected, while the prevailing maximum temperature is more than 10º C higher than the optimal range. Any fractional rise in temperature would therefore, have serious adverse effects on growth, maturity and productivity. Irrigation water requirements would increase to compensate heat stress, with the cooling of crops becoming an essential element of the crop production system (ITC Report, 2011).

Importance of Cotton in Pakistan Economy

Cotton contributes 5.1% value added in agriculture. During 2015-16 cotton was planted on 2,961 thousand hectares which illustrates 1.5 % reduction as compared to last year. Production of cotton during 2015-16 was found to be 13.960 million bundles (Technologytimes.pk). Cotton-wheat system is a dominant cropping system of Sindh province and southern Punjab areas of Pakistan (Byerlee et al. 1987). Cotton is a cash crop of Pakistan and it has 9.81 % share in global cotton. In 2011-12, Pakistan's yarn exports contributed 26.1% and 14.3% to global market. About 46% of Pakistan's total exports constitutes cotton and this sector is also providing 35% employment to labor force (FAOSTAT, 2012). According to Pakistan's current agriculture policy, CCC (Central Cotton Committee) has intended to increase the production of cotton from 40% to 60 % (Arsyad & Sodiq, 2014). As an important cash crop of Pakistan, it contributes to national economy and it is a key source of livelihood for the people living in rural areas (FAO, 2014). It is widely grown in hot and humid areas, where there are high pest hazards because some insects are especially deleterious to the yield and quality of cotton. There are many requirements for high yield of cotton, such as high input, fertilizers, chemicals for pest control, highly drained soil, and water, and their utilization deteriorates the environment in different ways (Rehman et al., 2016). The intensive input usage as a form of quality and yield insurance of cotton incurs high production costs. Both of the environmental hazards and high costs of productions threats the sustainability and farmer's own income in Pakistan. Therefore, analyzation and quantification of environmental conditions also impacts the cotton production in addition with the economic conditions.

Climate Change Threats To Pests Management:

Generally, climate change is associated with higher carbon dioxide levels, higher seasonal temperatures and more precipitation (IPCC, 2007). These global climate change effects will affect the pest distribution. Higher temperatures are often associated with increased rates of development, growth, and reproduction and hence the fear that plant diseases will become more severe makes intuitive sense. Warmer climate crops, such as those found in the tropics, tend to suffer greater pest problems than crops in more temperate regions (Lamichhane et al., 2015). In the current scenario, two factors are responsible for increasing potential pest pressure risk in agriculture. Anthropogenic impact, in particular increasing global movement of people and trade of plant commodities, continues to lead to the introduction of exotic pests into new regions. Climate change provides suitable conditions for such pests to adapt across the areas which were previously disadvantageous for their survival (Chakraborty 2013 & Fletcher et al. 2010). That is how, climate change further accelerates pest pressure both in space and time and may have dramatic consequences throughout specific regions of the globe. In some regions, excessively dry, wet, or warm conditions may directly hinder crop production and therefore current crop protection methods may become ineffective (Lamichhane et al., 2015). Pest adaptation to warmer temperatures have given rise to mounting disease epidemics in new areas where, in retrospect, the current cropping systems are excessively vulnerable to unforeseen threats. Even less direct effects, such as changes in crop or pest phenology can also have significant consequences in plant production. Crop losses due to pests can account of up to more than 40 % worldwide (Oerke, 2006).

These values might significantly rise under changing climatic conditions whereby new and more aggressive pests affect levels and stability of crop yield thereby threatening food security. However, it is not possible to make estimates on overall potential crop losses due to climate change (Chakraborty, 2013). Abiotically stressful environment in changing climate is predicted to impact negatively the diversity and abundance of insect-pests; and ultimately the extent of damage caused in economically important agricultural crops (Fand et al. 2012). Insect-pests of crop plants are the real candidates most affected by global climate change. Complex physiological effects exerted by the increasing temperature and CO2 may affect profoundly, the interactions between crop plants and insect-pests (Frances and Caulfield 1994). It has been reported that, global climate warming may lead to altitude wise expansion of the geographic range of insect-pests (Matthews et al., 2014), increased abundance of tropical insect species, decrease in the relative proportion of temperature sensitive insect population, more incidence of insect transmitted plant diseases through range expansion and rapid multiplication of insect vectors. Thus, with changing climate it is expected that the growers of crops have to face new and intense pest problems in the years to come (Fand et al., 2012).

Global warming & Climate change on insects:

According to Sharma 2014, Global warming and changes in climate will influence:

- Activity, diversity, and abundance of insect pests.
- Geographical distribution of insect pests.
- Development and population dynamics.
- Expression of host-plant resistance to insects.
- Pest outbreaks and pest invasion.
- Synchrony between plants and insect pollinators.

As a result of global warming, insects may find suitable alternative habitats at greater latitudes and higher altitudes. Genetic variation and multifactor inheritance of innate recognition of environmental signals may mean that many insect species will have to adapt readily to such disruption. Many species may also have their diapause strategies disrupted as the linkages between temperature, moisture regimes, and day lengths will be altered (Sharma, 2014).

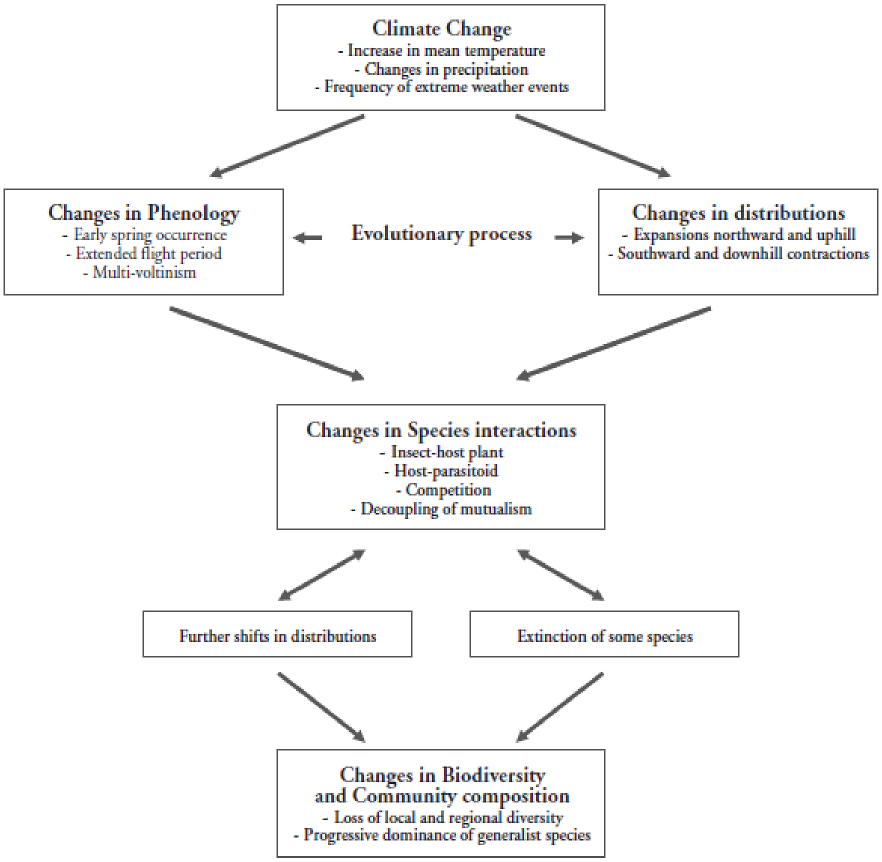

Figure 1: Insect response to global warming (Matthews et al., 2014).

Global average surface temperature has increased by around 0.6 ºC during the past century and will continue to rise in the future. Understanding how these changes in climate have affected biological systems has attracted a vast research effort during the last two decades. Insects are among the groups of organisms most likely to be affected by climate change because climate has a strong direct influence on their development, reproduction, and survival (Bale et al. 2002). Moreover, insects have short generation times and high reproductive rates, so they are more like to respond quicker to climate change than long-lived organisms, such as plants and vertebrates. Warming can potentially affect several aspects of insect life-cycle and ecology, especially those directly controlled by energy availability variables such as degree day which is accumulative temperature needed for development. Consequently, potential responses include changes in phenological patterns, changes in habitat selection, and expansion and contraction of geographic and altitudinal ranges (Menéndez, 2007).

Climate change can also affect insects in indirect ways, where the insect responds to climate-induced changes mediated by other factors. These other factors may include interaction with other species (competition, predation and parasitism) or for herbivorous insects, host plant. warming may affect the structure of existing communities because individual responses will inevitably alter species interactions, leading to changes in the composition of natural communities (Menéndez, 2007). Phenological changes are probably the best documented responses to recent climate change and have been detected for a wide range of organisms from plants to vertebrates (Lovejoy, 2008). Empirical evidence is also common within the uniramian taxa. Under a rise in temperature insects will pass through their larval stages faster and will become adults earlier. Thus, observed responses include both an advance in the timing of adult emergence and an increase in the length of the flight period. In this regard, Lepidoptera are by far the best documented group.

According to Sharma 2014, the possible impacts on insects under climate change are as listed below,

a) Climate change will alter selection pressures within populations because most populations are adapted to their local environments. Traits that confer fitness in an environment might not be as successful under new climatic conditions, and therefore it is imperative that evolutionary responses take place.
b) Changes in geographical range and insect abundance will increase the extent of crop losses and, thus, will have a major bearing on crop production and food security (Sharma, 2014). Increasing temperatures may impart greater ability to insect species limited by low

temperatures at higher latitudes to overwinter, extending their geographical range (Vadez et al., 2012).

c) Spatial shifts in the distribution of crops under changing climatic conditions will also influence the distribution of insect pests in a geographical region (Parry & Carter, 1989). For example, In North America and Europe changes in species distribution ranges have been documented in butterflies, where species have shifted their ranges northward and to higher elevations as a result of global warming (R. J. Wilson et al., 2005).

d) Increases of 1◦C and 3◦C in temperature would cause northward shifts in the potential distribution of the European corn borer, *Ostrinia nubilalis* (Hub.), up to 1220 km, with an additional generation in nearly all regions where it is currently known to occur(R. J. Wilson et al., 2005).

e) Large-scale changes in rainfall caused by global warming will also have a major bearing on the abundance and diversity of arthropods.

f) Responses of arthropods to pollution depend on both temperature and precipitation; ecosystem-wide effects are likely to increase under predicted climate change (Zvereva & Kozlov, 2010).

g) The main effects of climate change and pollution on arthropod communities will be a decreased abundance of decomposers and natural enemies and increased herbivory, which may have negative consequences for the structure and services of entire ecosystems. For example, an increase in the amount of rainfall in the pampas region of Argentina has been shown to affect species with poor dispersal capabilities (Canepuccia et al.2009).

h) Climate change will become a major factor for the extinction of arthropod species. Mountain species and those restricted to high latitudes are most likely to become extinct as a result of climate change. The species adapted to cold conditions will be forced to move uphill to higher latitudes as a result of global warming (Sharma, 2014).

Effect of climate change on geographic distribution of insect pests:

Climate change will have a major effect on geographic distribution of insect pests, and low temperatures are often more important than high temperatures in determining the distribution (Hill 1987; Thomas et al. 2001). A common approach in predicting developmental dynamics and migration of insects in relation to weather conditions involves the use of degree-day models. However, temperature does not act in isolation to influence pest status, and therefore it is important to consider interactions with other variables, such as rainfall, humidity, radiation, and CO_2 concentrations. Increasing temperatures may impart greater ability to insect species limited by low temperatures at higher latitudes to overwinter, extending their geographical range. Sudden outbreaks of insect pests can wipe out certain crop species and also encourage invasions by exotic species. Spatial shifts in the distribution of crops under changing climatic conditions will also influence the distribution of insect pests in a geographical region. However, whether or not an insect pest would move with a crop into a new habitat will depend on other environmental conditions, such as the presence of overwintering sites, soil type, and moisture (Sharma 2014).

Effect of fluctuating temperature on insects:

Species responses are expected to be idiosyncratic depending on the flexibility of different life-history characteristics. Bale et al. (2002) proposed that different growth rate and diapause requirements may influence distributional responses to climate change. Fast growing, non-diapausing species or those which are not dependent on low temperature to induce diapause, will respond to warming by expanding their distributions. In contrast, slow growing species which need low temperatures to induce diapause (such as boreal and mountain species in the northern hemisphere) will suffer range contractions. Thus, climate change will affect species ranges, with expansion in some species and contractions in others, which in turn will lead to changes in regional and local diversity (Menéndez, 2007).

Impacts of elevated CO_2 on insects:

Enriched atmospheric CO2 influences plant physiology, with direct consequences for plant productivity and biochemical composition. Plant chemical composition influences positive and negative trophic interactions, as well as decomposition, which will then feedback to atmospheric CO2 concentrations (Lindroth 2010). The increase in carbon availability for plant tissues and the consequent changes in the C/N ratio impact nitrogen levels in plant tissues, causing a "nitrogen dilution effect". This low nitrogen concentration, coupled with a high C/N ratio and its potential effects on plant secondary metabolism, means a lowered concentration of leaf protein and therefore reduced nutritive value to herbivores (Lincoln *et al* 1986. a recent meta-analytical study, Stiling 2007 reviewed the evidence for the indirect effects of elevated CO2 on several aspects of insect life history parameters and herbivory patterns from 75 studies that generated 405 independent comparisons. It was previously suggested that herbivores would respond to altered plant primary and secondary metabolism under elevated CO2 by increasing food consumption to compensate for the plant lowered nutritional quality by reducing their growth rates and prolonging their development time and by reducing food conversion efficiency. These reductions in herbivore performance under CO_2 enrichment would have the potential to increase mortality imposed by natural enemies ultimately reducing herbivore abundance, richness and diversity if compared to ambient CO2 conditions (Fig 1).In general, the results of the meta-analysis of demonstrated strong responses of herbivores to elevated CO2 conditions, such as;

1) Adecline in insect abundance of almost 22.0% in elevated as compared to ambient CO2 conditions
2) An increase of almost 17.0% in consumption rates.
3) An increase of almost 4.0% in development time.
4) A decrease of 9.0% in relative growth rate
5) 5.0% in pupal weight.

When results for the effects of CO2 were partitioned into feeding guilds (e.g., chewers, miners, gallers), stronger and significant effects of elevated CO2 were observed for chewers compared to other feeding guilds. However, the vast majority of studies so far conducted to address effects of elevated CO2 on herbivores have been biased to free-feeding herbivores and many more studies are necessary to obtain a clearer pattern of CO2 effects on other guilds of herbivores. For sap-sucking insects such as aphids, for example, it has been demonstrated that despite the studies carried out to evaluate aphid responses to changes in CO2 concentrations in the atmosphere, it is not yet possible to establish general rules nor to predict responses of aphid species, populations or even clones to global climatic changes (Cornelissen, 2011).

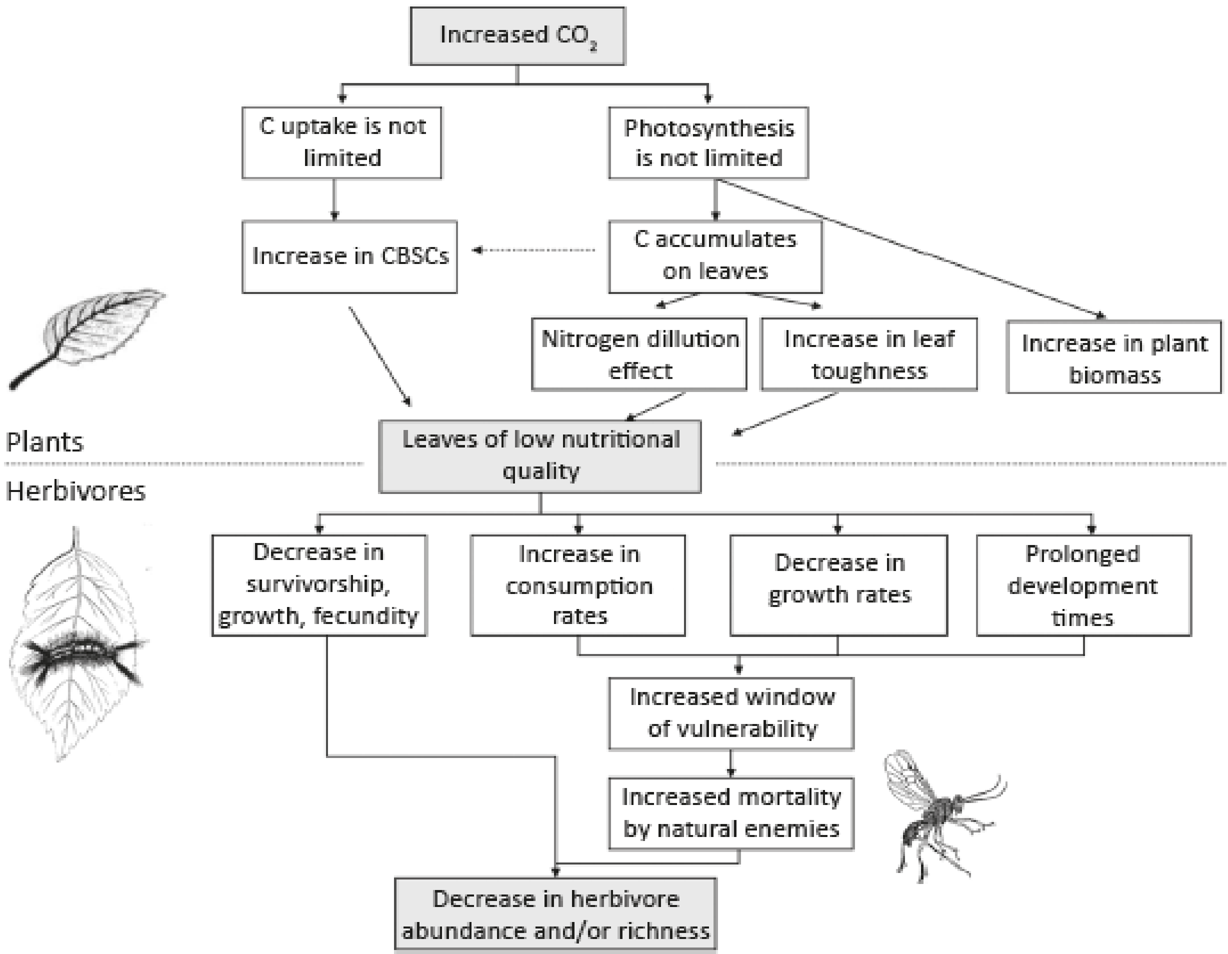

Figure 2:Predicted effects of elevated CO_2 conditions (Cornelissen, 2011)

Pests in Cotton

According to a survey undertaken by Arshad et al. 2009 from the farmers reveals that majority of farmers (60.7%) mentioned a low incidence of American bollworm (Helicoverpa armigera), while 20.0% reported medium and 13.3% high incidence of this pest. These estimates were based on insect pests and disease incidence. Most farmers were also aware of the incidence of the spotted bollworm (*Earias vitella* and *E. insulana*) a very destructive pest of cotton in Pakistan. Most of the farmers (54.7%) reported a low incidence of this pest in Bt cotton, 29.3% reported a medium, and 16.0% reported a high incidence. Another important pest of cotton is the monophagous pink bollworm (*Pectinophora gossypiella*), which farmers recognise by the formation of rosette flowers. They reported a low (47.3%), medium (30.0%) and high (14.7%) incidences, while only 8.0% gave no response. Army worm (*Spodoptera litura* and *S.exigua*) is a sporadic pest but in the 2003–2004 cotton seasons it caused a major loss to the cotton crop and has become a major pest of cotton in the Punjab province. Many farmers (40.7%) reported a low incidence in Bt cotton, while 30.7 and 28.6% reported medium and high incidences, respectively. Whitefly (*Bemisia tabaci*) is very important as it is a vector of cotton leaf curl virus (CLCV), which may lead to crop failure in Pakistan. Many farmers (46.7%) reported a high incidence, while 37.3% reported a medium and only 16.0% of respondents reported a low incidence of this pest . The second most important sucking pest is the cotton jassid (*Amrasca devastans*). Many farmers (41.3%) reported a high incidence of this pest while 33.3% reported a medium and only 16.0% mentioned a low incidence. Approximately 34.0% of respondents gave no response in the case of thrips (*Thrips tabaci*) due to difficulty in its identification (Arshad et al., 2009). All of these incidences are depicted below in the figure 1.

	Low	Medium	High	No response
Whitefly				
No. (% respondents)	24 (16.0)	56 (37.3)	70 (46.7)	0 (0.00)
Age a (b)	0.004 (0.952)	0.32 (0.573)	0.35 (0.555)	–
Education a (b)	0.010 (0.919)	1.95 (0.163)	1.64 (0.201)	–
Jassid				
No. (% respondents)	24 (16.0)	50 (33.3)	62 (41.3)	14 (9.3)
Age a (b)	0.13 (0.718)	0.39 (0.532)	0.15 (0.697)	0.66 (0.418)
Education a (b)	0.22 (0.642)	0.09 (0.769)	0.02 (0.890)	1.68 (0.195)
Thrips				
No. (% respondents)	21 (14.0)	34 (22.7)	44 (29.3)	51 (34.0)
Age a (b)	0.065 (0.799)	2.97 (0.085)	1.01 (0.316)	0.56 (0.455)
Education a (b)	1.138 (0.286)	1.03 (0.309)	0.07 (0.789)	0.02 (0.888)
Aphid				
No. (% respondents)	25 (16.7)	58 (38.6)	36 (24.0)	31 (20.7)
Age a (b)	0.97 (0.323)	0.004 (0.952)	0.68 (0.408)	0.001 (0.971)
Education a (b)	1.46 (0.227)	0.274 (0.600)	2.10 (0.147)	0.045 (0.832)
Cotton mealybug				
No. (% respondents)	34 (22.7)	29 (19.3)	48 (32.0)	39 (26.0)
Age a (b)	1.39 (0.238)	0.06 (0.808)	0.32 (0.570)	0.09 (0.762)
Education a (b)	1.48 (0.223)	0.22 (0.641)	0.004 (0.950)	2.72 (0.099)

a, linear-by-linear association; (b), *P* value.

Figure 3:Farmers' perception of the incidence of some major sucking insect pests in Bt cotton (Total farmer ¼ 150).

Strategies and methods for insect-pest evaluation in Pakistan:

In Pakistan, the temperature in May and June are as high as 40º C to 45º C, often reaching 50º C on individual days. Winter temperatures often fall below freezing in the Punjab and upper Sindh but the lower Sindh is frost free. Two distinct cropping seasons for summer (*Kharif*) crops, from April to October, and winter (*Rabi*) crops, from October to April/May. Some short-season crops are sandwiched between these main cropping seasons. The main crops are wheat, cotton, rice and sugarcane (ITC report, 2011). Insect-pests substantially reduce yields of staple grains rice, maize, and wheat. The relationships between temperature, population growth and metabolic rates of insects could be established to estimate how and where climate warming will enhance losses of rice, maize, and wheat to insects. Crop losses will be most acute in areas where warming increases both population growth and metabolic rates of insects (Deutsch, et.al 2018). The distribution of various climate-related risks across study districts are summarized in Fig. 4 below. In Rahim Yar Khan, the five most important climate-related risks identified by farmers were animal diseases, insect attacks, extreme maximum temperature, human diseases and crop pests. Similarly, in Toba Tek Singh and Gujrat, extreme maximum and minimum temperature, animal diseases, crop pests and insect attacks were the five most reported climate-related risks at farm level (Abid, et al. 2016).

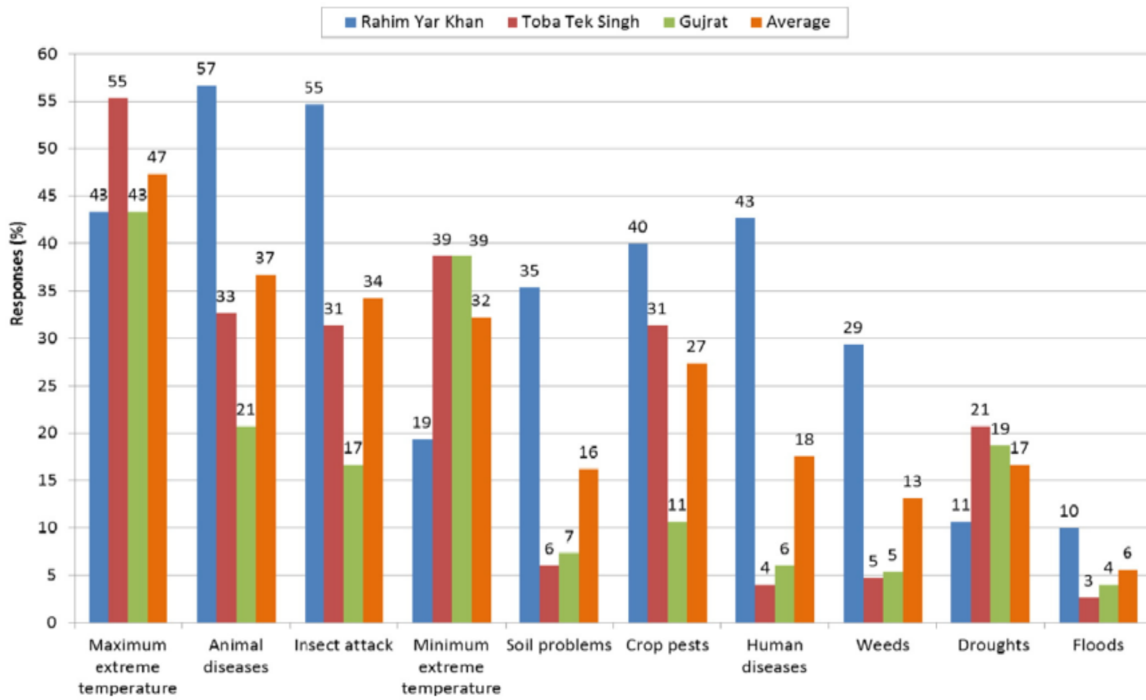

Figure 4: Perceived climate-related events in the past decade in Punjab, Pakistan (Abid, 2016)

The above graph shows the results of survey done by Abid et, al.2016. In this graph, the responses of farmers were evaluated in the three districts of Punjab, Pakistan. The average temperature comes out to be 34% and in Rahimyar Khan amplified value of insect attack was observed which was found to be 55%. Similarly crop pests were also estimated 40% in Rahimyar Khan. The average crop pests were observed as 27%. Maximum temperature in summers cause heat stress in rice leading to reduction in pollination and grain numbers (Rasul et, al. 2011). A warmer climate will alter at least two agriculturally relevant characteristics of insect pests. First, an individual *insect's metabolic rate* ***(M)*** accelerates with temperature, and an insect's rate of food consumption must rise accordingly. Second, the *number of insects* ***(n)*** will change, because population growth rates of insects also vary with temperature. The total energy consumption of a pest “population metabolism” is proportional to the product of these two factors and directly relates to the *crop yield loss* **(L)** caused by insect herbivory. Fractional changes in *pest-induced crop losses* (**DL/L)** can thus be partitioned into a *metabolic component* **(DM/M)** and a *demographic component* **(Dn/n)** (13). The sum of these fractional changes approximates the total *fractional change in yield loss* n (et. a. 2018 Deutsch, 2018). The formula comes out to be,

$$\frac{\Delta L}{L} = \frac{\Delta M}{M} + \frac{\Delta n}{n}$$

These three staple crops are grown in different climates, where warming can induce opposite changes in insect population growth rates, diapause survival differentially affects losses of these three crops. For wheat, which is typically grown in relatively cool climates, warming will increase pest population growth and overwinter survival rates, leading to large population increase in the growing season (Fig. 5). In rice, which is grown in relatively warm tropical environments, the same population dynamic has the opposite impact, warming there should reduce insect population growth rates and thus partly counteract the rising crop losses due to increased insect metabolism, allowing global rice production lost to insects to stabilize for warming exceeding~3°C (Fig. 5B). For maize, the demographic effect has only a small net impact on global production losses, because this crop is grown in some regions where population rates will increase and in other regions where population rates will decline, in nearly equal measure (Fig. 5C) (Deutsch, et. a. 2018).

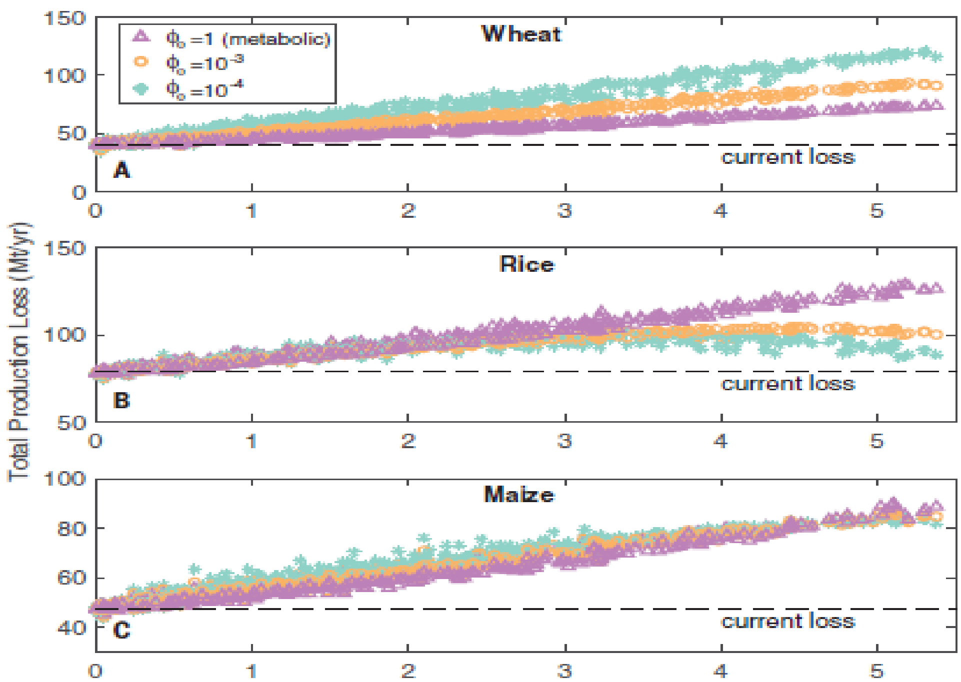

Figure 5: Global loss of crop production owing to the impact of climate warming on insect pests. Crop production losses for (A) wheat, (B) rice, and (C) maize are computed by multiplying the fractional change in population metabolism by the estimated current yield loss owing to insect pests, summed over worldwide crop locations. Results are plotted versus mean global surface temperature change, for four climate models , for two different values of the demographic parameter governing survival during diapause (fo = 0.0001, asterisks; fo = 0.001, circles), and for the metabolic effect alone (triangles). Mt/yr, metric megatons per year (Deutsch et al. 2018).

These all results are based on the models to predict future changes in population growth and metabolic rates. Projected monthly surface temperature anomalies were added from

climate model simulations under a "business-as usual" emissions scenario (RCP8.5). A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory adopted by the IPCC for its fifth Assessment Report (Stocker, Allen, Bex, & Midgley, 2013)

The most substantial yield declines will occur in many of the world's most productive agricultural regions, thus reducing global grain availability. Our analysis focuses on the changing impacts of insect pests on crop yields with an increase in global temperature, accounting for the most robust general responses of insect pests to temperature. The full scope of physiological and ecological impacts is likely to be complex and sensitive to particular crop-pest interactions for which more physiological data will be needed, especially among tropical pest species. These interactions will occur in conjunction with direct plant responses to warming and rising CO2 levels, which, for the three major crops that we considered, are predominantly negative. However, scenarios with added or alternative biological dynamics, such as thermoregulation by insects or increased diapause mortality with warming, suggest that the dominant patterns described here are robust , and species-specific predictions for pests that affect these three crops generally agree with our predictions. Agricultural practices will shift as the climate warms. Changes in planting dates, cultivar use, and planting locations are already under way and will become more pronounced as the rate of climate warming increases. Our results suggest that farmers will need to make additional changes, such as introducing new crop rotations, to maintain yields in the face of rising insect pest pressure. In intensive agricultural environments, adaptation measures may involve greater pesticide use, at the cost of associated health and environmental damage and the elevated threat of pesticide resistance. Without wider attention to how climate warming will affect crop breeding and sustainable pest management strategies, insect driven yield losses will result in reduced global grain supplies and higher staple food prices. Poor grain consumers and farming households, who account for a large share of the world's 800 million people living in chronic hunger, will suffer most (C. A. Deutsch, et al. 2018).

Models, simulations and scenarios for observing climate change impacts on insects:

Ecological or meteorological models describe biological or climate properties mathematically, while simulations make a computer based models system supplied with a great amount of empirical data . Method of climatic reconstruction (MCR) is a method that simulates realistic climate data in the past. Simulated weather data, however, are most commonly used to examine the potential future effects. These approaches are called scenario studies. The main problems that have to precede scenario studies are, nevertheless, the evaluation, the validation and verification of the applied models.

Time-dependent models developed at fine spatial resolution of experimental studies are widely used to forecast how plant – insect populations will react over large spatial extents. Usually the best data available for constructing such models comes from intensive, detailed field studies. Models are then scaled-up to coarser resolution for management decision-making investigate the integrated effects of insect infections, management practices, carbon cycle and climatic factors both at regional and global scales.

The Forest Vegetation Simulator (FVS) is a distance-independent, geographic region dependent individual-tree forest growth model that has been widely used in the United States for about 30 years to support management decision making. It has been continuously extended, improved and adapted to further management tasks like prediction of climate change effects. Component models predict the growth and mortality of individual trees, and extensions to the base model represent disturbance agents including insects, pathogens, and fire. The geographic regions are represented by regionally specific model variants. The differences are due to data availability and the applicability of existing models. The model supports specification of management rules in the input.

Boll Weevil DISPersal Model (BWDISP) is a stochastic simulation model that predicts the spread of boll weevil populations on cotton. Because the development and dispersal of this insect is sensitive to temperature, it is important to understand how this insect will potentially respond to climate change. In addition, without proper management of this pest, other secondary pests may attack the crop.

Northern Corn ROOTWORM Model is a process – oriented simulation model that examines the population dynamics of corn – rootworm in the northern United States. The rootworm attacks both the roots and tassels of corn, decreasing yields. The model examines how planting date affects the population dynamics of the insects. It gives information on phenology and the number of individuals in each growth state of corn. The model can analyse global change impact on the population levels and distribution of the insects, as well as the potential economic impacts.

Insects as bio-indicators of climate change:

Arthropods can be used as good bioindicators of human-driven changes in the environment, such as pollution, habitat loss, and fragmentation, and monitoring of terrestrial arthropods can provide early warnings of ecological effects attributable to climate change. Insects can also be used as examples of how biodiversity and community structure are affected by climate change. However, we still have a long way to go in understanding the detrimental and beneficial effects of human-induced climate change on biological systems. Arthropods can serve as good indicators of environmental change more easily than vertebrates and plants. For monitoring purposes, indicator assemblages should exhibit varying sensitivities to environmental changes and show diversity in life history and ecological interactions. Realistic information on arthropod diversity must be integrated into policy planning and management practices if ecosystems are to be managed for use by future generations. Ecosystem baselines that document arthropod species assemblages that are comparable in space and time are important for the interpretation and implementation of strategies designed to mitigate the effects of global warming and climate change (Sharma, 2014).

Cotton crop protection from pests:

Cultivation of cotton (*Gossypium hirsutum L.)* is a highly extensive type of farming that requires excessive utilization of resources to protect the crop from insect pests, and synthetic chemicals are used extensively for better crop growth (Deguine et al., 2008). In addition, with the factors responsible for low cotton yield, insects are ranked at the top of the biotic agents that not only deteriorate the quality of cotton produce but also reduce the yield. Farmers cannot afford highly protective measures due to small land holdings in most of developing countries, and their extensive use leads to environmental pollution (Fitt, 2000). Plant pathogens is another important aspect of cotton cultivation, which is declared a serious threat to some areas, but their importance is less than that of other factors, such as inputs and agrochemicals (Gross, 2017). Although large amounts of synthetic chemicals are used in cotton farming, losses account for almost 29 percent despite the use of pest control measures.

Chemical usage for crop production:

In today’s world, agricultural productivity depends upon the utilization of chemicals and it is a well-known and extensive method for integrated pest management. Therefore, it is an integral part of agricultural systems. Synthetic chemicals have helped farmers to manage common pests easily and effectively that would otherwise pose a serious threat of reduced crop yield (Carvalho, 2006). Crop protection has increased with increased use of synthetic chemicals and fertilizers in cotton crops, resulting in an overall increase in the yield of cotton crops (Damalas & Eleftherohorinos, 2011).

Pesticides usage including insecticides, fungicides, herbicides, rodenticides protects crops from different pests, allowing significant reduction in the losses and to improve the crop yields of maize, vegetables, cotton, potatoes etc. Pesticides are the poisons which are intentionally dispersed in the environment to control pests, but they also cause side effects on non-targeted species. Their residue also contaminates the water and soil and can remain in the crops and ultimately enter the food chain (Carvalho, 2006). Insect pests had developed resistance to insecticides and as a consequence chemical companies start synthesizing new chemicals. In European union, more than 800 chemicals are registered as pesticides, however their effect on environment and health is little known (Street, 2003).

Sustainability of cropping systems:

From climate change, sustainability of current cropping systems are under threat and likely to be impacted. Global food production must increase by 50% to meet the anticipated demand of growing world population by 2050. Climate change is further complicating this challenge as it influences the crop-pests distribution like insects, weeds, pathogens and disease severity (Lamichhane et al., 2015).

Tackling pests by introduction of Bt cotton:

In Pakistan, serious pests of cotton include, Cotton bollworms (American bollworm, pink bollworm and spotted bollworm). They cause huge damage and the intensity varies each year differently. Generally 30%-40% reduction in yield is observed due to pests (Abro et al.2004). Farmers rely heavily on the use of pesticides to control cotton bollworms. It is estimated that they spend US$300 million on pesticides annually, of which more than 80% is used on cotton, especially for control of Bollworms (Arshad et al., 2009). Use of transgenically modified Bt cotton that expresses an insecticidal protein toxin derived from Bacillus thuringiensis Berliner (Bt) is revolutionising global agriculture (Head et al., 2006).

Integrated Pest Management:

In pest management, number of issues have to encountered like damage due to a number of key pests, insecticide resistance in the primary pest, secondary pests, escalating costs of production of insecticides etc.To address these issues, major research effort has focused on reducing dependence on insecticides through the development and implementation of integrated pest management (IPM) systems. In Australia, the Australian cotton IPM system emphasises the use of a range of tools to manage pest populations, with insecticides seen as a last resort. Higher emphasis is placed on the role of beneficial insects in IPM which is unique about the approach taken in Australia. The heavy involvement of cotton growers and consultants in the development of the system emphasis on incorporating IPM as a component of the overall farming system. The role of IPM groups, where neighbouring growers agree on a common set of IPM goals, communicate regularly and support one another to achieve group goals (L. J. Wilson, Mensah, & Fitt, 2004).

Sustainable IPM will also need considerable input from the plant itself. The cotton plant is not simply a substrate for the interaction of pests and chemicals, it is the template on which a broad range of interactions occur between the pests and their environment. Cotton has a number of both morphological and biochemical traits which impart varying degrees of pest tolerance (Fitt, 2000). Through conventional breeding some of these have been introduced into commercial varieties and provide incremental gains in pest tolerance. There remains much genetic variability in insect resistance traits and in the potential of cotton to compensate for damage (Sadras & Fitt, 1997). This genetic resource has not been fully exploited by breeders, but should be in order to provide a more resilient plant background for pest management (Bottrell, Barbosa, & Gould, 2002). One of the greatest impediments to development of IPM in cotton has been the lack of tools to control target pests without also disrupting these beneficial populations. While predators and parasitoids are important components of IPM systems and in many cases their potential value can also be overstated. Severe limitations in the capacity of beneficials to control some pests, particularly the Heliothines need to be recognised. These pests are highly mobile, highly fecund, well adapted to exploit diverse cropping systems (Fitt, 2000).

The main purpose of insect pest management is to identify the pest species and to exclude them in order to prevent their influence. Exclusion of pests is one of the first lines of defense whether undertaken at the fields through quarantine sanitary and phytosanitary measures. With an increase in globalization and free trade the necessity for effective suitable procedures are essential for countries to prevent invasion from imported alien species. Imported species can become invasive, presenting a major threat to the sustainability of natural systems and agricultural productivity. Pests reduce yields and income through pest management costs. Existing plant health services are often outmoded and under-resourced to face the demands of free trade in a competitive and demanding new environment. National systems are sometimes poorly equipped to predict and manage the threat posed by alien invasive species. There is a need for sanitary and phytosanitary provisions in trade; a dire need for effective systems, balanced yet rapid to support free trade and prevent the introduction of injurious pest species (Williams & Il'ichev, 2009).

International Insect Pest Management Strategies:

IPM strategies have been successfully implemented in a few countries and regions of the world. In some cases this has helped in reducing the overuse and misuse of pesticides and in other cases it has promoted the use of biological control for sustainable pest management. Globalization of the agriculture and food system is increasingly demanding foods produced in a safe and environmentally friendly way. The experiences from Asia, Africa and Latin America indicate that specific IPM packages have been developed and successfully adopted for the management of a single pest in a specific crop. Developing and implementing IPM for multiple pest, disease and weed complexes affecting crop production in developing countries has been difficult and progress in this area has been limited. According to Williams and Il'ichev 2009 , the general constraints to the development and implementation are as under:

1. Lack of national IPM policy and many countries do not have a national IPM policy.
2. Lack of institutionalization of IPM to help develop and coordinate IPM programs.
3. Lack of a multi-disciplinary approach leading to inadequate problem identification and poor project design for the development and implementation of IPM. Current IPM packages have been based on the management of a single pest, leading to the outbreak of the secondary pests.
4. Lack of appropriate research to develop technologies and integration of various tactics to be used in IPM programs. The majority of the IPM packages have focused on the use and integration of one or two tactics. This has exerted selection pressure on pests to develop resistance. There has not been a good integration of various pest management tactics.
5. Lack of well-trained human resources, research facilities, financial resources, and institutional linkages (lack of collaboration among various government departments and ministries). IPM is a multi-disciplinary approach. Plant protection specialists must collaborate and work hand-in-hand with breeders, agronomists, social scientists, and specialists from all other appropriate disciplines.
6. IPM is an information intensive strategy. Farmer participation in the design, development and implementation of IPM packages is critical. The research, extension and farmer linkages are critical for the information flow and successful implementation of IPM. The stakeholders

include local and national governments, farmers or commodity organizations, academia, NGOs, private sector, international organizations, and the donor community (Williams & Il'ichev, 2009).

Farmer participation and empowerment in IPM:

Monitoring of pests and beneficial organisms is the basis of any IPM program. Government extension services or private agencies should conduct area-wide monitoring and provide the appropriate information on pest outbreaks to farmers on a regular basis. Training and education of farmers and other workers in pest identification, monitoring and management approaches should be provided. Farmer participation and empowerment is critical for the adoption of IPM packages. The weather data should be utilized in the development of predictive models for forecasting the outbreaks of pests, especially migratory pests. New and emerging technologies such as mating disruption using sex pheromone technologies are increasingly utilized in commercial agriculture. However, the use of such technologies is complex and very information intensive. Therefore, these technologies must accompany appropriate information on their use. Success in IPM relies on well-trained and skilled human resources. Education, training and development of appropriate human resources will allow the formation of multidisciplinary IPM teams for planning, designing, development and implementation of IPM packages for specific crops or ecosystems. A special emphasis should be given to train personnel in IPM project management, experiment station management, and IPM-related business development. In most countries, IPM programs function in isolation with very poor coordination among people working in different departments and ministries. IPM must be institutionalized to provide a better planning and coordination at both institutional and national level. For example, the Indian Government has established a National Center for IPM (Williams & Il'ichev, 2009).

Future anticipations:

Indeed, the main consequence of climate change and accelerated globalization is a heightened level of unpredictability regarding spatial and temporal interactions between weather, cropping systems, and pests (Chakraborty, 2013). This is the highest ongoing crop protection challenge that farmers, advisers, researchers, and policy makers face (Lamichhane et al., 2015). In order to reduce crop losses due to either invasive or rapidly evolving resident pests under changing climate, the further integration of the roles of plant health and crop protection specialists for the creation of more resilient cropping systems appears increasingly relevant. Such recognition, although still rather tentative and subject to further policy integration and elaboration, is consistent within the framework of adaptive strategy needs (En L, 2002).

Conclusion:

- Global warming and climate change will trigger major changes in arthropod diversity, geographical distribution of insect pests, insect population dynamics, herbivore–plant interactions, activity and abundance of natural enemies, and efficacy of crop protection technologies for pest management.
- Distribution of insect pests and their natural enemies will also be influenced by changes in the cropping patterns triggered by climate change.
- Global warming will also reduce the effectiveness of host plant resistance, transgenic plants, natural enemies, biopesticides, and synthetic chemicals for pest management.

- Predicting the impact of climate change on insects is a very complex exercise and a one that involves a great deal of modeling.The precise impacts of climate change on insects is somewhat uncertain because some climate changes may favors insects while others may inhibit a few insects.
- More work is required to identify the effects of weather and climate on important agricultural pests and determine the climatic variables to which different species are most sensitive.
- Therefore, there is a need to generate information on the likely effects of climate change on insect pests to develop robust technologies that will be effective and economical in the future under global warming and climate change.

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