Alexandria University
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(ARCA)

# Climate change impacts on pests and pesticide use

*A review article*

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ISSN 2314-8874
9 772314 887004

***July 2014***

***ARCA Working Paper***

***Working Paper No. (3)***

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# 1. Introduction

The Environmental Protection Agency (US EPA) defines pesticide as "any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest". A pesticide may be a chemical substance or biological agent (such as a virus or bacteria) used against pests. Farmers in the hot spots are overburdened with increasing costs of cultivation, a deleterious credit system, and declining productivity, increased incidences of pests and diseases, and spurious pesticides. The sole reliance on chemical pesticides for plan protection has created serious problems. In addition, problems of pest outbreaks, resistance and resurgence of pests demand more pesticides.

Pesticides have been the center of controversy for a long time and are associated with risks to human health and/or to the environment. On the other hand, society accepts these risks within certain limits as there are also benefits linked to the use of pesticides, in particular in agricultural production. Overuse of pesticides has brought about a decline in the bio-diversity of non-target organisms in the hot spots. The respondents in the hot spots revealed that a significant decline in population of birds, earthworms, natural predators like green lacewing, *Chrysoperia carnea*, lady bird beetles, spiders, *A panteles spp., Trichogramman spp., Cheloanus, black burni,* etc., was noticed in their field. Long-term changes of climate have already been detected and there is wide agreement that the climate will continue to warm over the 21st century (IPCC, 2001a; 2001b). Global warming might increase pest activity.

Insects and other arthropods are potentially useful taxa for examining the direct and indirect effects of changes in climate over time. Unlike many other taxa, insects exist over a wide range of temporal and spatial scales. Insect populations can respond rapidly, allowing researchers to identify study foci from ongoing monitoring. In plain words, insects live short lives, are everywhere, and respond quickly to subtle changes in habitat. This quick response makes insects particularly suitable as candidate species for monitoring changing environments. In addition, monitoring insect populations is generally inexpensive, and often requires a minimal investment in equipment and training. For these reasons, insects are potentially an important source of sentinel information for climatic effects on other higher order taxa. Insects are poikilotherms, consequently their life history parameters are directly linked to temperature (Beresford, and Sutcliffe, 2009; Beresford, 2011). Insects have optimal temperatures for maximal survival and population growth, a variety of different life history responses to sub-optimal temperatures, and temperature minima and maxima beyond which insects either enter developmental stasis or die. Because of this, insect populations, physiological growth, and other life history parameters are measured in accumulated degree days above (and below) developmental temperature thresholds, symbolized as ADD lower threshold, and commonly standardized against 0, 5 or 10 $^{o}$ C thresholds.

This direct linkage between growth and temperature makes insects and other arthropods powerful tools for assessing climatic effects on a region's habitat and diversity.

An important indirect effect of a warming trend concerns late season agricultural pests. These currently require pesticide applications to control their numbers after reaching economic injury levels, usually in midsummer after populations increase over several generations. Under warming temperatures such pests may require spraying earlier in the summer, adding an additional burden of increased pesticide to the environment.

Several entomologists and biologists have investigated the potential effects of climate change on pest populations (Patterson *et al*., 1999; Porter *et al*., 1991). They confirm that projected warming will help some pest species to survive winters and will accelerate the development of summer-active species. In any particular location, climate change may not mean more pest animals and weeds, but it could mean new pest animals and weeds. The range of pests will generally shift to higher latitudes as a result of warming trends. On the one hand, an increase in extreme events, such as cyclones, storms and associated floods, may increase the dispersal of weed species that rely on wind and water to move seeds or pollen. On the other hand, habitats disturbed by extreme events such as drought, leave empty niches which pest animals and weeds could colonize. In addition, there is evidence that pests often recover from extreme climatic events faster than other species.

Therefore, the use of pesticides may increase and subsequently the negative impacts on society and the environment may be amplified. Although the range of studies conducted in the field of climate change agriculture–environment interactions is wide, the information on climate change pesticide-use environment interactions is quite limited. Such interactions have to be addressed and taken into consideration in the formulation of climate change mitigation and adaptation policies.

It is the greatest environmental challenge of the 21st century. But what do we truly know about global climate change? And what can we do about it? Evidence shows that global climate change is occurring. Research and debate continue on the role of increasing atmospheric concentrations of greenhouse gases in influencing climate change. Many sectors are or will be influenced by changing climate and climate variability, including increasing global temperatures, changing precipitation patterns, and increased frequency of unusual weather events. Agriculture and the world's supply of food and fiber are particularly vulnerable to such climate change. Effects of Climate Change and Variability on the Agricultural Production Systems provides an integrated assessment of global climate change's impact on agriculture at the farm level, in the context of farm level adaptation decisions.

Global climate change is arguably the most severe problem that the World faces today. Our climate influences every aspect of life on this planet from our ability to produce food and therefore our future development, to the distribution of biomes and the level of biodiversity that exists in the world – much of which remains scientifically unclassified or unknown. The earth's climate has changed over the last century and there is new and stronger evidence that most of the warming observed the last 50 years is attributable to human activities. The degree to which climate change affects our lives must not be taken lightly. Take for example the increase in extreme weather conditions around the World producing devastating droughts in some regions, flooding in others and a generally greater propensity for cyclones, tornadoes and hurricanes due to increased oceanic temperatures. Many of us will be fortunate enough to never experience the destructive forces of nature but if we continue to upset natures, various equilibrium and these events could become the norm for majority of the world's population.

It is important that developing countries have their own capacity to assess their national vulnerability to climate change and plant adaptation strategy accordingly. Assessment of vulnerability requires an estimate of the impacts of climate change, which in turn is based on scenarios of future climate.

# 2. Objective

The main objective of this working paper is to understand and review the impacts of expected climate change on pests and potential pesticides use. Moreover, the working paper aims to review various adaptation options to minimize such impacts.

# 3. Climate change and pests: risk analysis

More than 10,000 insects, 600 weeds and 1,500 fungi, commonly named pests, adversely affect daily human life. They reduce the quality and quantity of food produced, by lowering production and destroying stored produce, compete with humans for food and cause a variety of diseases to humans, animals and crops.

Humans began to control pests at the same time as they started farming. Over the years several pest management systems have been applied: manual removal of weeds and animal pests, cultivation breaks for vulnerable crops, mechanical soil treatment, biological pest control, genetic engineering and use of chemical pesticides. Across all available pest management systems, pesticides have become the most frequently selected alternative for pest control.

Once disseminated to the environment, pesticides may cause changes in the natural biological balances and may reduce biodiversity. Since pesticides are designed to be toxic to living species, they may also adversely affect human health. Worldwide, the application of 3 million metric tons of pesticide, results in more than 26 million cases of human pesticide poisonings. Of all the pesticide poisonings, about 3 million cases are hospitalized and there are approximately 220 000 fatalities and about 750 000 chronic illnesses every year. There is some evidence that poisoning from exposure to pesticides may cause neurological, respiratory and reproductive disorders, sensory disturbances, cognitive problems and cancer (Teitelbaum *et al*., 2007; Cockburn 2007; Alavanja *et al.*, 2006).

Bearing in mind these adverse impacts, in the 1960s researchers began developing a different approach to pest control called “integrated pest management” (IPM). The integrated pest management approach claims to keep pests at economically tolerable levels through a diverse set of control strategies, which discourage pests, promote beneficial predators or parasites that attack pests and time pesticide applications to coincide with the most susceptible period of the pests’ life cycles. However, even with integrated pest management, pesticides are frequently the only way to deal with emergency pest outbreaks (Delaplane 2007). Therefore, agriculture may be able to reduce the inputs of chemicals, but their complete elimination is currently economically not feasible. While political leaders, citizens, and government officials try to mediate and resolve conflicts between the risks and benefits of pesticide use by producing safer chemicals, selective pesticides, better application methods and stronger pesticide admission rules, climate change is likely to expand these conflicts.

## 3.1. Areas of impact

Weeds, insects, and pathogen-mediated plant diseases are affected by climate and atmospheric constituents. Resultant changes in the geographic distribution of these crop pests and their vigor in current ranges will likely affect crops.

### (a) Weeds

Weeds may benefit from the “$CO_2$ fertilization effect” and from improvements in water use efficiency associated with increasing $CO_2$ concentrations, but the impact on crop production will depend on how enhanced-growth weeds compete with enhanced-growth crops.

Regarding temperature, most weeds of warm season crops originate in tropical or warm temperate areas and are responsive to small increases in temperature. For example, the growth of three leguminous weeds increased significantly as day/night temperature increased (Flint *et al.*, 1984). Biomass of C4 smooth pigweed (*Amaranthus hybridus*) increased by 240% for an approximate 3°C temperature increase; C4 grasses also showed large increases (Patterson 1993). Accelerated range expansion of weeds into higher latitudes is likely (Rahman and Wardle 1990; Patterson 1993) as demonstrated for itchgrass (*Rottboellia cochinchinensis, Lour*.), cogongrass (*Imperata cylindrica*), Texas panicum (*Panicum texanum*), and Witchweed (*Striga asiatica*) (Patterson *et., al.,*, 1999). However, not all exotic weeds will be favored by climatic warming. Patterson et al. (1986) found loss of competitiveness under warmer conditions for the southward spread of wild proso millet (Panicum miliaceum) in the southwestern United States.

Increasing $CO_2$ and climate change probably will also affect mechanical, chemical, and natural/biological efforts to control weeds (Patterson, 1993), which currently cause worldwide crop production losses of about 12% (25% for traditional production systems). Environmental factors including temperature, precipitation, wind, soil moisture, and atmospheric humidity influence when herbicides are applied, as well as their uptake and metabolism by crops and target weeds. On the other hand, increased temperatures and increased metabolic activity tend to increase uptake, translocation, and effectiveness of many herbicides. Natural and biological control of weeds and other pests depends on the synchrony between the growth, development, and reproduction of biocontrol agents and their targets. Such synchrony may be disrupted if climate changes rapidly, particularly if climatic extremes occur more frequently. Global warming could facilitate overwintering of insect populations and favor earlier pole ward migrations in the spring, which could increase the effectiveness of biological control of weeds in some cases. Conversely, such enhanced over-wintering would accelerate the spread of viruses by migrating vectors like aphids.

**(b) <u>Insects</u>**

Climate and weather can substantially influence the development and distribution of insects. Current estimates of changes in climate indicate an increase in global mean annual temperatures of 1°C by 2025 and 3°C by the end of the next century. Such increases in temperature have a number of implications for temperature-dependent insects, especially in the region of Middle-Europe. Changes in climate may result changes in geographical distribution, increased overwintering, changes in population growth rates, increases in the number of generations, extension of the development season, changes in crop-pest synchrony of phenology, changes in interspecific interactions and increased risk of invasion by migrant pests (Memmott *et al*., 2007; Parmesan 2007; Porter *et al*., 1991).

Under the climatic changes projected by the Goddard Institute for Space Studies general circulation model, northward shifts in the potential distribution of the European corn borer of up to 1220 km are estimated to occur, with an additional generation found in nearly all regions where it is currently known to occur (Porter *et al*., 1991). Several results on the effect of climate change on insects were published in the field of forestry sciences, since insects cause considerable loss of wood that has an adverse effect on the balance of carbon sequestered by forests. Volney and Fleming (2000) state that pests are major, but consistently overlooked forest ecosystem components that have manifold consequences to the structure and functions of future forests. Global change will have demonstrable changes in the frequency and intensity of pest outbreaks, particularly at the margins of host ranges

Ayres and Lombardero (2000) have shown that climate change has direct effects on the development and survival of herbivores and pathogens; physiological changes in tree defences; and indirect effects from changes in the abundance of natural enemies (e.g. parasitoids of insect herbivores), mutualists (e.g. insect vectors of tree pathogens), and competitors. Because of the short life cycles of insects, mobility, reproductive potential, and physiological sensitivity to temperature, even modest climate change will have rapid impacts on the distribution and abundance of many kinds of insects. To consider scenario studies, some of them predict negative, but many forecast positive effects on insects. E.g. global warming accelerates insect development rate and facilitate range expansions of pests, moreover, climate change tends to increase the vulnerability of plants to herbivores. One alarming scenario is that climate warming may increase insect outbreaks in boreal forests, which would tend to increase forest fires and exacerbate further climate warming by releasing carbon stores from boreal ecosystems (Ayres and Lombardero, 2000).

Climate variability at decadal scales influences the timing and severity of insect outbreaks that may alter species distributions. Coops *et al*. (2005) have presented a spatial modelling technique to infer how a sustained change in climate might alter the geographic distribution of the species. Using simulations they produced a series of maps that display predicted shifts of zones where the species they examined might expand its range if modelled climatic conditions at annual and decadal intervals were sustained. The connection between temperature tolerance and phenology of insects was investigated by Klok and Chown (2001). They defined how current climate change like increased temperature and decreased rainfall affect on physiological regulation and susceptibility.

Powell and Logan (2005) have reviewed the mathematical relationship between environmental temperatures and developmental timing and analysed circle maps from yearly oviposition dates and temperatures to oviposition dates for subsequent generations. Applying scenarios for global warming they proved that adaptive seasonality may break down with little warning with constantly increasing (and also decreasing) temperature.

Forecasted increases in atmospheric $CO_2$ and global mean temperature are likely to influence insect – plant interactions. Plant traits important to insect herbivores, such as nitrogen content, may be directly affected by elevated $CO_2$ and temperature, while insect herbivores are likely to be directly affected only by temperature. Fuhrer (2003) stated that insect populations did not change significantly under elevated $CO_2$, but tended to increase slightly. Average weight decreased at high temperatures. Plant height and biomass were not significantly affected by the $CO_2$ treatment, but growth rates before infestation were enhanced by elevated $CO_2$. These results indicate that the combined effects of both elevated $CO_2$ and temperature may exacerbate pest damage to certain plants, particularly to plants which respond weakly to increases in atmospheric $CO_2$.

Up to this time, mainly two climatic factors – temperature and humidity have been investigated. Though, it is possible that some parts of solar radiation have at least the same importance in controlling insect populations. Last, but not least, changes in climate increase the likelihood of insect transport from regions to regions, as well (Ladányi and Horváth, 2010).

It should be noted that global climate change impact on plant - pest populations depends on the combined effects of climate (temperature, precipitation, humidity) and other components like soil moisture, atmospheric $CO_2$ and tropospheric ozone ($O_3$). Changes in agricultural productivity can be the result of direct effects of these factors at the plant level, or indirect effects at the system level, for instance, through shifts in insect pest occurrence. With respect to crops, the data suggest that elevated $CO_2$ may have many positive effects, including yield stimulation, improved resource - use efficiency, more successful competition with weeds, reduced $O_3$ toxicity, and in some cases better pest and disease resistance. However, many of these beneficial effects may be lost at least to some extent in a warmer climate. Warming accelerates plant development and reduces grain-fill, reduces nutrient-use efficiency, increases crop water consumption, and favors weeds over crops. Also, the rate of development of insects may be increased (*Karuppaiah and G.K. Sujayanad*, 2012).

A major effect of climate warming in the temperate zone could be a change in winter survival of insect pests, whereas at more northern latitudes shifts in phenology in terms of growth and reproduction, may be of special importance. However, climate warming disturbs the synchrony between temperature and photoperiod; because insect and host plant species show individualistic responses to temperature, $CO_2$ and photoperiod, it is expected that climate change will affect the temporal and spatial association between species interacting at different trophic levels. Although predictions are difficult, it seems reasonable to assume that agro – ecosystem responses will be dominated by those caused directly or indirectly by shifts in climate, associated with altered weather patterns, and not by elevated $CO_2$ per se. Overall, intensive agriculture may have the potential to adapt to changing conditions, in contrast to extensive agricultural systems or low - input systems which may be affected more seriously (Fuhrer, 2003).

Crop protection in Europe became strongly chemically oriented in the middle of the last century. An excellent climate for fast reproduction of pests and diseases demanded high spray frequencies and, thus, resulted in quick development of resistance against pesticides. This initiated a search for alternatives of chemical pesticides, like natural enemies for control of pests. A change from chemical control to very advanced integrated pest management programs (IPM) in European greenhouses took place at the end of the last century (Kogan and Jepson, 2007). For the main greenhouse vegetable crops in northern Europe, most insect problems can now be solved without the use of insecticides. IPM without conventional chemical pesticides is a goal that will be realized for most of the important vegetables in Europe, not limited to greenhouse vegetables. At the same time, however, climate change affects the distribution, the phenology, the susceptibility and the interrelationship of insects drastically, which emphasize the risk of sustainable crop protection by losing the control on pests – natural enemies' populations.

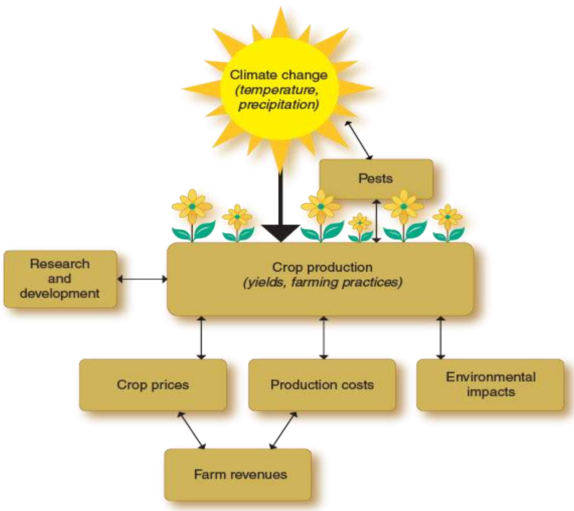


Figure (1): Impacts of climate change on crop production

Source: Ladányi and Horváth, 2010

- **Impacts of higher temperatures**

Temperature has potential impacts on plant disease through both the host crop plant and the pathogen. Research has shown that host plants such as wheat and oats become more susceptible to rust diseases with increased temperature; but some forage species become more resistant to fungi with increased temperature (Coakley et al 1999). Many mathematical models that have been useful for forecasting plant disease epidemics are based on increases in pathogen growth and infection within specified temperature ranges. Generally, fungi that cause plant disease grow best in moderate temperature ranges. Temperate climate zones that include seasons with cold average temperatures are likely to experience longer periods of temperatures suitable for pathogen growth and reproduction if climates warm. For example, predictive models for potato and tomato late blight (caused by Phytophthora infestans) show that the fungus infects and reproduces most successfully during periods of high moisture that occur when temperatures are between 45$^{o}$ F (7.2 $^{o}$ C) and 80 $^{o}$ F (26.8 $^{o}$ C) (Wallin and Waggoner, 1950; FAO,1995). Earlier onset of warm temperatures could result in an earlier threat from late blight with the potential for more severe epidemics and increases in the number of fungicide applications needed for control.

- **Impacts of moisture change**

Moisture can impact both host plants and pathogen organisms in various ways. Some pathogens such as apple scab, late blight, and several vegetable root pathogens are more likely to infect plants with increased moisture – forecast models for these diseases are based on leaf wetness, relative humidity and precipitation measurements.

Other pathogens like the powdery mildew species tend to thrive in conditions with lower (but not low) moisture. More frequent and extreme precipitation events that are predicted by some climate change models could result in more and longer periods with favorable pathogen environments. Host crops with canopy size limited by lack of moisture might no longer be so limited and may produce canopies that hold moisture in the form of leaf wetness or high canopy relative humidity for longer periods, thus increasing the risk from pathogen infection (Coakley *et al.,* 1999). Some climate change models predict higher atmospheric water vapor concentrations with increased temperature – this also would favor pathogen and disease development.

- **Impacts of rising $CO_2$ levels**

Increased $CO_2$ levels can impact both the host and the pathogen in multiple ways. Some of the observed $CO_2$ effects on disease may counteract others. Researchers have shown that higher growth rates of leaves and stems observed for plants grown under high $CO_2$ concentrations may result in denser canopies with higher humidity that favor pathogens. Lower plant decomposition rates observed in high $CO_2$ situations could increase the crop residue on which disease organisms can overwinter, resulting in higher inoculum levels at the beginning of the growing season, and earlier and faster disease epidemics. Pathogen growth can be affected by higher $CO_2$ concentrations resulting in greater fungal spore production. However, increased $CO_2$ can result in physiological changes to the host plant that can increase host resistance to pathogens (Coakley *et al.,* 1999).

**(c) Plant Diseases**

The study of plant disease often begins with a discussion of the “plant disease triangle”. The three legs of the triangle – host, pathogen, and environment – must be present and interact appropriately for plant disease to result. If any of the 3 factors is altered, changes in the progression of a disease epidemic can occur. The major predicted results of climate change increases in temperature, moisture and $CO_2$ can impact all three legs of the plant disease triangle in various ways. Precisely predicting the impact of climate change on plant disease is tricky business (Friedrich, 1994).

## 3.2. Implications

Conditions are more favorable for the proliferation of insect pests in warmer climates. Longer growing seasons will enable insects such as grasshoppers to complete a greater number of reproductive cycles during the spring, summer, and autumn. Warmer winter temperatures may also allow larvae to winter-over in areas where they are now limited by cold, thus causing greater infestation during the following crop season. Altered wind patterns may change the spread of both wind-borne pests and of the bacteria and fungi that are the agents of crop disease. Crop-pest interactions may shift as the timing of development stages in both hosts and pests is altered. The possible increases in pest infestations may bring about greater use of chemical pesticides to control them, a situation that will require the further development and application of integrated pest management techniques.

There is a fine balance between pests and disease-causing organisms (known as pathogens) and their host plants. It is possible however to make two generalizations: stressed trees are more susceptible to insect pests and diseases, and the majority of insect pests that currently affect are likely to benefit from climate change as a result of increased summer activity and reduced winter mortality. Some insect pests that are currently present at low levels, or that are not considered a threat at this time, may become more prevalent (Reilly, 1995).

**(a) <u>Insect population</u>**

Climate change is likely to alter the balance between insect pests, their natural enemies and their hosts. One of the most important effects of climate change will be to alter the synchrony between host and insect pest development, particularly in spring, but also in autumn; the predicted rise in temperature will also generally favor insect development and winter survival, although there will be some exceptions, changes have already been observed in the distribution of native butterfly populations.

Most studies have concluded that insect pests will generally become more abundant as temperatures increase, through a number of inter-related processes, including range extensions and phenological changes, as well as increased rates of population development, growth, and migration and over-wintering. Global warming will increase pest populations, including weeds, invasive species, insects, and insect-borne diseases, which will likely lead to large increases in the use of pesticides. The effects of climate change are already beginning to be seen, and will continue to be seen for years to come. Without drastic actions to curb global warming, the current course we are heading on will lead to booms in pest populations and pesticide use. In plant communities, high levels of carbon dioxide stimulate the growth of invasive plant species more than native species. Additionally, as carbon dioxide increases, herbicides may become less effective at controlling invasive weeds. In addition to increasing weed populations; global climate change is expected to increase the frequency and the intensity of insect outbreaks through direct effects of climate change on insect populations, as well as through disruption of community interactions (Green facts, 2007; Ladányi and Horváth, 2010).

Researchers have found that insect species that adapt to warmer climates also will increase their maximum rates of population growth, meaning that global warming will likely lead to increased insect populations. The study's say that this "warmer is better" and phenomenon is likely to have widespread effects on agriculture, public health and conservation. With the boom in insect populations, scientists also hypothesize that there will be increases in insect-borne diseases such as malaria, dengue fever, and viral encephalitis. Scientists believe that climate change will increase disease transmission by shifting insects' geographic range, increasing reproductive and biting rates of the insects, and by shortening the pathogen incubation period (Ladányi and Horváth, 2010).

Physiological and biochemical changes induced in host crop plants by rising $CO_2$ may affect feeding patterns of pest insects. Compilation of climatic thresholds for phonological development of pest insects reveals the potential for shifts in pest behavior induced by global warming and other climatic change. Generation times may be reduced, enabling more rapid population increases to occur. The epidemiology of plant diseases also will be altered.

Prediction of disease outbreaks will be more difficult in periods of rapidly changing climate and unstable weather. Environmental instability and increased incidence of extreme weather may reduce the effectiveness of pesticides on targeted pests or result in more injury to non-target organisms.

Biological control may be affected either negatively or positively. Overall, the challenge to agriculture from pests probably will increase. Plant responses to ultraviolet radiation include reduced leaf size, stunted growth, poor seed quality, and increased susceptibility to weeds, disease, and pests. Climate change may bring new opportunities (e.g.new crop options), but also will pose new risks and challenges for farmers and specifically:

- Invasive insect, disease and weed pests are likely to benefit most from climate change, leading to increased pesticide and herbicide use;
- Reductions in biodiversity are likely, because climate change will tend to favor aggressive invasive at the expense of endangered species that are poor at migrating and adapting to change.

Many of the predicted consequences of climate change, such as increasing temperatures, changes in rainfall patterns, and more erratic or extreme weather events, will have impacts on pollinator populations. Such changes might affect pollinators individually and ultimately their communities, reflected in higher extinction rates of pollinator species (UNEP, 2010; Tirado *et al*., 2013). For example, it has been documented how honeybees in Poland are responding to changes in climate by advancing the date of their first winter flight (the wakening moment after winter), part of a phenomenon often known generally as “season creep”. The first winter flight date has advanced by over one moth during 25 years of observations, and this is attributed to increasing temperatures (Sparks *et al*., 2010). In addition to species level effects, climate change will very likely affect the interaction between pollinators and their sources of food, i.e. flowering plants, by inter alia changing the dates and patterns of flowering. Recent analysis has suggested that between 17% and 50% of pollinator species will suffer from food shortages under realistic scenarios of projected climate change that cause modified plant flowering pattern plants (Memmott *et al.*, 2007). The authors concluded that the anticipated result of these effects is the potential extinction both of some pollinators and some plants and hence the disruption of their crucial interactions (Memmott *et al.*, 2007). In conclusion, climate change in addition to its predicted impacts in the form of species extinctions may also lead to "the large-scale extinction of interactions which are responsible for a key ecosystem service, that of the pollination of plants."

**(b) Fungal diseases**

The impact on pathogens whose reproduction or dispersal is clearly affected by temperature is relatively predictable. Warmer summers may in particular favor certain thermophilic rust fungi. Warmer winters may increase the activity of some weak pathogens. An increased incidence of summer drought would probably favor diseases caused by fungi whose activity is dependent on host stress; particularly root pathogens (Petzoldt and Seaman, 2008).

## 3.3. Climate variability and pests

Increased variability in rainfall and changes in temperature will likely disrupt key ecosystem processes such as phonology and will influence insect pests and diseases in mostly unknown ways. Direct effects on pests will involve disruption of insect life cycles or creation of more suitable conditions for new pests (or for old pests to expand their territory). Extreme meteorological events, such as spells of high temperature, heavy storms, or droughts, disrupt crop production. Recent studies have considered possible changes in the variability as well as in the mean values of climatic variables.

Karuppaiah and Sujayanad (2012) studied the impact of climate change on population dynamics of insect pests. The studies showed that, declined survival rate of brown plant hopper *Nilaparvatha lugens* (Stal) and rice leaf folder, *Cnaphalocrocis medinalis* (Guen) at higher temperature indicates the impacts of rising temperature could do the changes in the pest population dynamics of rice ecosystem. The alteration in the voltinism also could be the results of warming and it is more profit to multivoltine species and voltinism could be reflected in changes in the geographical distribution. Beside these, elevated CO also showed some impact on pest's population abundance, the crop grown under the elevated $CO_2$ could alter the nutritional value of plants; it may alter the insect abundance and increase the consumption rate of herbivores. Therefore climate change would result in changes in the population dynamics of insect pests. Thus temperature rise plays a pivotal role in insect population dynamics.

## 3.4. The toxicology of climate change

Climate change will have a powerful effect on the environmental fate and behavior of chemical toxicants by altering physical, chemical, and biological drivers of partitioning between the atmosphere, water, soil/sediment, and biota, including: air-surface exchange, wet/dry deposition, and reaction rates (e.g., photolysis, biodegradation, oxidation in air). Temperature and precipitation, as altered by climate change, are expected to have the largest influence on the partitioning of chemical toxicants (Henriksen *et al*., 2013) In addition, an array of important processes, such as snow and ice melt, biota lipid dynamics, and organic carbon cycling, will be altered by climate change potentially producing significant increases in fugacity (thermodynamic measure of substance tendency to prefer one phase over another) and contaminant concentrations. Other potential interactions between climate change and toxicant exposure include increased susceptibility to pathogens (Abadin *et al., 2007*)

Driven by climate changes, pest development rates and/or host-plant susceptibility to pests can be altered. It is expected that changes in the climate (warming of the earth atmosphere, increased rain fall, extreme drought,...) and the accompanying emerging diseases and influence on pesticide behavior (e.g. increased precipitation, faster degradation due to higher temperature, loss due to wash off by rainfall, decreased activity under dry conditions,...) will increase the use (and costs) of pesticides for certain (new) crops. This was documented for Brazil where excessive rains in 2004 favored the development of soybean rust leading to an increased use of fungicides to control the disease.

# 4. Climate change and pesticides: international experience

This section discusses the impacts of climate change on pests and pesticides use types in the case of some international experiences at both of continental and national levels

## 4.1. Continental level

**(a) AFRICA**

Jarvis, *et al*, (2010, 2011) examined the impacts of climate change on cassava production in Africa, and questions whether cassava can play an important role in climate change adaptation. First, they examined the impacts that climate change will likely have on cassava itself, and on other important staple food crops for Africa including maize, millets, sorghum, banana, and beans based on projections to 2030. Results indicate that cassava is actually positively impacted in many areas of Africa, with –3.7% to +17.5% changes in climate suitability across the continent. Conversely, for other major food staples, we found that they are all projected to experience negative impacts, with the greatest impacts for beans (-16% ± 8.8), potato (-14.7 ± 8.2), banana (-2.5% ± 4.9), and sorghum (-2.66% ± 6.45). They then examined the likely challenges that cassava will face from pests and diseases through the use of ecological niche modeling for cassava mosaic disease, whitefly, and brown streak disease and cassava mealy bug. The findings show that the geographic distribution of these pests and diseases are projected to change, with both new areas opening up and areas where the pests and diseases are likely to leave or reduce in pressure.

They found that the abiotic traits of priority for crop adaptation for a 2030 world, showing that greater drought tolerance could bring some benefits in all areas of Africa, and that cold tolerance in Southern Africa will continue to be a constraint for cassava despite a warmer 2030 world, hence breeding needs to keep a focus on this trait. Importantly, heat tolerance was not found to be a major priority for crop improvement in cassava in the whole of Africa, but only in localized pockets of West Africa and the Sahel. They concluded that cassava is potentially highly resilient to future climatic changes and could provide Africa with options for adaptation whilst other major food staples face challenges.

Global warming is adversely affecting the earth's climate and its profound effects are virtually on all ecosystem. Every living animal will be affected in one way or another by climatic changes and insects being an integral biotic component of nearly all ecosystems are not an exemption. However, the various ways by which change will occur is yet to be determined by scientists. Insects being an integral biotic component of nearly all ecosystems will be affected by the change in a variety of ways not yet determined by scientists. Ayieko *et al.,* (2010) reviewed how edible lake flies in Lake Victoria and termites in the lake region are responding to climate change and how they are likely to impact on entomophagy and gastrophagy as part of food chain among the riparian communities.

The amounts and pattern of emergence of insects during the onset of rainy season has been influenced by the changes in the weather patterns. They found that periodicity of emergence of the insects has been influenced by the unpredictability of the onset of the rain season and other weather activity on which the emergence of the insects depend on but these influences are yet to be explored. It is expected that the climate change will have both positive and negative impacts on collection and utilization of edible insects for human consumption and livestock feeds formulation. The status of food security of the marginal areas around the Lake Victoria will depend on how scientists interpret and manage the climate change outcomes. The reducing number of swarming aquatic insects in certain areas is attributed to environmental pollution as a result of the global warming.

The relationship between insects, plants and climate may elicit new kinds of behaviour yet to be determined. It is interesting to note that researchers have tended to record potential climate change effects of insects on human and animal health (Petzoldt and Seaman, 2008; Marigi *et al*., 2005; Marigi and Wairoto, 2005). This is particularly so, due to threats of increased transmission of pathogens. Resulting dynamics of effects of climate change on insects and plants may not necessarily be due to any single player but to their interactions. In any case, it is not certain that such interaction will maintain ecosystem stability, or lead to biodiversity instability (Bredenh, 2008.). This is an issue yet to be researched more for future effective management. The interrelationship between moisture and temperature and the insect population may create new insect dynamics in the tropics with widespread influence on riparian communities. New things do happen with change! For example, Dunn and Crutchfield (2006) say that due to climate change, pine beetles have been noted to do things which have not been recorded before. The insects are attacking younger trees and attacking timber in altitudes they have never been before.

**(b) Europe**

A recent study has assessed how climate change could affect the impact of European insect pests on forests to help develop effective forest protection strategies. Changing temperatures may cause some populations of insects to grow or move into new regions of Europe. The consequences of climate change for forest ecosystems will vary according to a number of factors: the region, the exact changes in weather patterns, the level of atmospheric carbon dioxide, levels and changes to the amount of ultraviolet radiation and sunlight falling on the forests. This research, conducted as part of an EU commissioned study and under the EU PROMOTH project, examined both the direct and indirect effects of climate change on insects that feed and live on forest trees (Netherer and Schopf, 2010). Rising temperatures will directly affect the insect life cycles, which will be completed earlier and more offspring will be produced in a season. The timing of flight development and spread of insect populations will be also directly affected by increasing temperatures. In addition, warmer conditions may directly benefit insects with low frost resistance, such as the green spruce aphid, whereas species that need a period of dormancy to complete their life cycle and survive cold winters could suffer, such as the larch bud moth. Warmer winter temperatures will allow some plant-eating insects, such as the pine recessionary moth, to move further uphill and attack previously unaffected mountain pine stands.

Insects will also be indirectly affected by the impact that climate change has on trees and forest structures. Increased $CO_2$ levels or drought stress would change plant chemistry, and this could reduce the nutritional balance of trees. In some cases, the host plant would develop increased resistance to insect attack (for example, through *tougher foliage*), reducing the survival and growth rates for some chewing insect pests. In other cases, climate change could reduce plant resistance, to the benefit of other insect species, such as bark beetles (Karuppaiah and Sujayanad, 2012)

Climate change will also affect the current ranges of different insect herbivores. Higher temperatures in the northern distribution range (the alpine region and boreal zone) are likely to result in some defoliating insects and bark beetles' range expanding further northwards. In contrast, in parts of the Mediterranean and temperate continental zones, increased temperatures and the higher chance of drought will affect heat-sensitive insects: this could force a northward expansion but also a reduced range in the south. As a heat-tolerant species, the pine recessionary moth will benefit from warmer conditions. To improve strategies to protect forests from insect pests under climate change, the researchers recommend: improving our understanding of the relationship between climate and insect species, from individuals to whole forest communities, as well as identifying, evaluating and monitoring physical (abiotic) and biological (biotic) risks (Netherer and Schopf, 2010).

## 4.2. National level

**(a) USA**

Weather and climate affect many agricultural decisions including crop choice, water management, and crop protection. During the past decades, average global temperatures have increased and there is wide agreement that the climate will continue to warm over the 21st century (IPCC, 2007). Koleva, *et al*. (2009). Studied the impact of weather variability and climate change on pesticide applications in the US. They used panel data regression for the US, they found that weather and climate differences significantly influence the application rates of most pesticides. Subsequently, the regression results are linked to downscaled climate change scenario the Canadian and Hadley climate change models. The application of most pesticides increase under both scenarios. The projection results vary by crop, region, and pesticide.

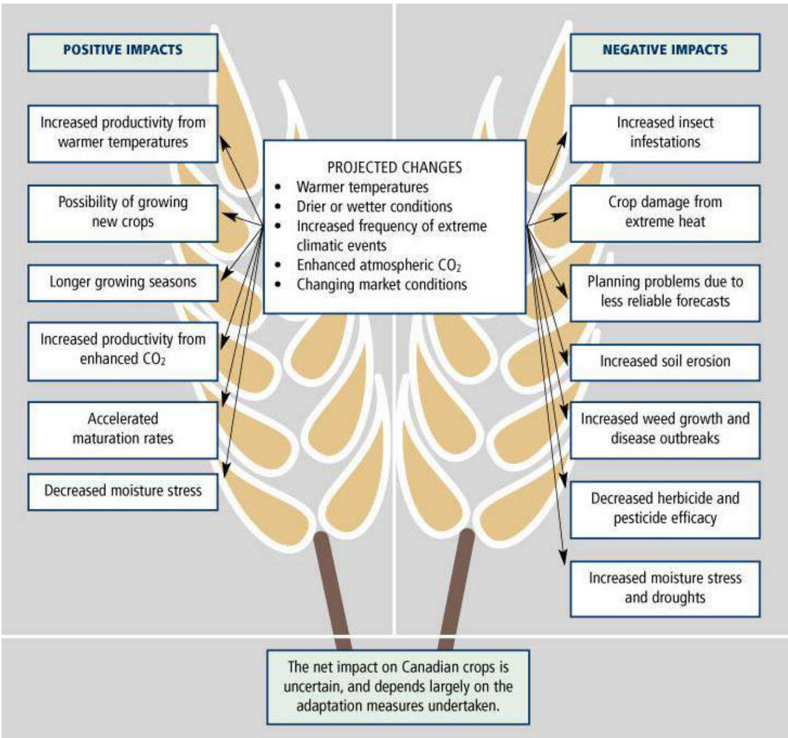


Figure (2): Potential impacts of climate change on agricultural crops in Canada
Source: Reilly et al, 1996

Pesticides used in agricultural production affect environmental quality and human health. These external costs can amplify due to climate change because pest pressure and optimal pesticide application rates vary with weather and climate conditions. Koleva, *et al.*, (2011) used mathematical programming to examine alternative assumptions about regulations of external costs from pesticide applications in US agriculture. They used two climate projections given by the Canadian and Hadley climate models. The impacts of the internalization of the pesticide externality and climate change are assessed both independently and jointly. They found that, without external cost regulation, climate change benefits from increased agricultural production in the US may be more than offset by increased environmental costs. The internalization of the pesticide externalities increase farmers' production costs but increase farmers' income because of price adjustments and associated welfare shifts from consumers to producers. Our results also show that full internalizations of external pesticide costs substantially reduces preferred pesticide applications rates for corn and soybeans as climate change.

Most global climate models predict that rainfall patterns will change and that storms will increase in severity (Koleva *et al*, 2009). The cumulative effects of these changes on plants and insects in California's agricultural and natural ecosystems are likely to be substantial. Trumble and Butler (2009). Reviewed that the elevated carbon dioxide concentrations and increasing temperatures associated with climate change will have substantial impacts on plant-insect interactions, integrated pest management programs and the movement of nonnative insect species into California.

Natural ecosystems will also be affected by the expected changes in insect diversity. Many insects will alter how much they eat in response to changing plant nutrition. Also, they can expect increased problems with many pest insects as they develop more rapidly in response to rising temperatures. If we hope to maintain sustainable agro-ecosystems and preserve native species in our natural ecosystems, we need to begin preparing now for the challenges of our changing environment.

### (b) TAIWAN

Taiwan is located in the subtropical nearby the tropical region. In Chia-nan area of central Taiwan, the average temperature during rice transplanting period of the first cropping season (from January to February) is about 14-18℃ (lowest average temperature is 12-14℃), and for the second cropping season is about 26-28℃ (highest averaged temperature is around 32℃) from July to August (Cheng, 2002). The major rice insect pests in Taiwan include the native species, immigrant species and invasive species. The yellow stem borer *Scripophaga incertulas* (Walker), striped rice borer [*Chilo suppressalis* (Walker)], pink borer [*Sesamia inferens* (Walker)], smaller brown *planthopper* [*Laodelphax striatella* (Fallen)], green rice leafhopper [*Nephotettix cincticeps* (Uhler)], rice *hispa* [*Dicladispa armigera* (Olivier)] and rice leaf beetle [*Oulema oryzae* (Kuwayama)] are the native species. The immigrant species, such as brown planthopper (*Nilaparvata lugens* Stål), whitebacked planthopper (*Sogatella furcifera* Horváth) and rice leaffolder [*Cnaphalocrocis medinalis* (Guenée)], can overwinter with a low population in Taiwan, but the population abundance mainly depend on the number of immigrants. The invasive species, such as rice water weevil (*Lissorhoptrus oryzophilus* Kuschel), invade into Taiwan mostly through international trade. Among them, rice leaf beetle and rice water weevil are the obligatory univoltine species and will diapause on adverse environmental conditions in Taiwan (Cheng, 2002;

Cheng and Huang, 2009).

Due to the global warming, winter temperature will become more suitable for pest overwintering if the host plants are available, and the brown plant hopper, white backed plant hopper and rice leaf folder and so on, may not only decrease the mortality in winter generation but also accelerate the rate of development and thus increase the opportunity to build up and damage on crop in the following generations (Kiritani, 2007).

The high temperature is usually not favorable to the development of some insects in summer, while other insects are able to adapt or decrease the injury by physiological or habitat accommodation.

Many researchers have proved that insect is varied in its genetic variability and some may tolerate to high temperature (Huey *et al.*, 1991, Quintana and Prevosti, 1990). The heat tolerance of mired in Thailand is about 30 times higher than that of the Philippine's strain. These results showed that insects may adapt in high temperature environment by selection and evolution. For some insect pests, such as smaller brown plant hopper, rice leaf beetle, rice water weevil, Taiwan is considered their south most distribution area. Higher temperature in summer may cause them disappear or become the minor insect pests. Contrarily, for those insect pests that Taiwan is considered as their north most distribution limit, such as green rice leafhopper [*Nephotettix virescens* (Distant)], temperature increase may help the insect to become more abundant (Cheng, 2002). Results from a long-term monitoring of the rice insect pests in Taiwan suggest that population of many insect pests, including the native and immigrated species, increase greatly during the past 10 years (Huang *et al*., 2009a).

Global warming could also induce some important tropical insect pests invading Taiwan. For instance, the Asian rice gall midge (*Orseolia oryzae* (Wood-Mason)) distributed in South and Southeast Asia (included southern China) may invade and settle down in Taiwan. Besides, surveillance on other important insect pests of rice in tropical area, such as white rice borer [*Scirpophaga innotata* (Walker)], dark-headed striped stem borer [*Chilo polychrysus* (Meyrick)], rice leafhoppers [*N. virescens* (Distant), N. *malayanus Ishiha* & Kawase] and Malayan rice black bug [*Scotinophara coarctata* (Fabricius)], are also needed when temperature is getting higher. The migratory rice insect pests occur mainly in East Asia. It is believed that the occurrence of emigration of migrants in the source area will become earlier and abundant due to global warming. Attention should also be paid to the changes of the immigrant properties; including pest species, chemical resistance and biotype, and associated diseases they transmitted. Any change in the properties may result a serious problem of pest management in immigrated area, including Taiwan (Cheng 2009; Huang *et al*., 2009b).

Accompanied with the faster development of rice insect pests, it is conjectured that rice insect pests may have higher population densities and overlapping generation in paddy fields. We believe that successive monitoring of the species and population changes in paddy fields is the priority need to be done than others. If the insects are key pests, then their population fluctuation, potential ability of damage and their relative biological and ecological characters have to be studied carefully, and then a control plan can be drew up, modified and set up finally. There are many measures can be used for curbing rice insect at present. The biological and physical controls are the well-known measures to most rice farmers, so as cultural practices and chemical spraying. However, each control method has its own virtues and defects, it is impossible to suppress the pests to an acceptable level by applying any control method alone. Therefore, a combination of more than one method to curb the population of insect pests below an economic threshold level has been suggested, the so-called “integrated control” or “integrated pest management”. The concept of integrated pest management is also adoptable in the case of climate change (Cheng, 2002). At present, the impacts of climate change on population dynamics and distribution of rice insect pests remain unpredictable. It is not easy to propose an appropriate tactic for controlling the insect pests in the future. However, based on experience and strategy of insect pest control used in tropical area, the integrated pest management approach seems feasible and applicable (Huang et al, 2009a; Huang et al, 2009b).

**(c) <u>EGYPT</u>**

Egypt has an arid climate with a relatively warm winter from November to April and a hot summer from May to October. Winter temperatures in Cairo range between 8.8° Celsius (°C.) and 18.2°C.; the summer temperatures between20.5°C. and 33.3°C. In Upper Egypt, the winters are mild; maximum temperature ranges from 19°C. to 23°C. and minimum temperatures are around 4.7°C. to 9°C. Summers are hot in the daytime and warm at night, with maximum temperatures from 34°C. to 40.8°C., and minimums from 19°C. to 25°C. Rainfall is almost entirely limited to the northern coastal region and a few kilometers inland, where the average annual rainfall ranges from 65-190 mm. The Nile Delta and adjacent areas receive 25-65 mm of rainfall annually. Areas south of Cairo, in Middle and Upper Egypt, average about 25 mm annual rainfall. With very little cloud cover, sunshine falls on the ground surface well over 90% of the possible time (Abdel Wahed, 1983).

Fahim *et al.,* (2011) studied the impacts of climate change, with warmer and more variable weather, on tomato diseases in Egypt. Its aim is to elucidate how warmer temperatures and an increase in extreme weather events may affect the incidence of some tomato fungal diseases in recent years. Recent climate trends, such as increased nighttime and winter temperatures, may be contributing to the greater prevalence of tomato diseases. The ranges of several important tomato disease in Egypt; including tomato late blight (the most destructive tomato disease causing fruit yield losses) have expanded since the early 1990s, possibly in response, in part, to climate trends. Wet vegetation promotes the germination of spores and the proliferation of fungi. Based on analysis of plant/disease/climate relations, an epidemic of late blight onset on tomatoes that is 1-2 weeks earlier means 2-3 additional sprays to achieve sufficient control of late blight. Accordingly, 1-3 more sprays will be applied at the incoming decades of the 2025-2100. The combination of long-term change (warmer average temperatures) and greater extremes suggest that climate change could have positive impacts on main tomato diseases in Egypt. There is a need for a better impact assessment of climate change on plant pests and diseases.

The potato tuber worm, *Phthorimaea operculella Zeller*, is a serious pest of potato, *Solanum tuberosum L.*, in subtropical and tropical production systems around the world. Potato tuber moth is considered among the most important potato insect pests in Egypt. The aim of this study was to predict degree day's unit and annual generation peaks for tuber worm under current and expected future climate by using the relationship between the accumulated thermal heat units expressed as degree-days unit (DDU) and the population fluctuations. It is evaluated how temperature influences the annual generation in two distinct locations in Egypt using the climate change data output from the HadCM3 model for A1 scenario proposed by the Intergovernmental Panel on Climate Change. The results indicated that population of the tuber worm at Ismailia gave the highest number of generations as compared with EL Beheira location under current climate (Tables 1 and 2).

Generation numbers of tuber worm under climate change conditions increased especially in Ismailia location. However, the expected generation numbers of the tuber worm in 2050 and 2100 are expected to be 9-11 and 10-12 generations per year, respectively. As a conclusion, the effect of climate change is expected to have asignificant effect on the ecological parameters of *Phthorimaea operculella* (i.e., generations). (Abolmaaty, *et. al.*, 2011).

*Pear Pyrus* communis is a deciduous fruit tree of economic importance that is widely grown successfully in many countries, including Egypt. However, its cultivated area in Egypt is very small compared to other fruit crops as mango, citrus, grapevine and peach and is presently decreasing. The reduction in production has resulted in fruit importation. Locally, wide range of insect species attack pear trees, causing a significant and serious loss in the yield production. Little data are available on pear crop pests in Egypt.

Osman and Mohamed (2008) surveyed the insect and mite pests attacking pear trees at Ismailia Governorate, Egypt, throughout two successive years 2005–2006 in two pear orchards of Suez Canal University. The survey covered the existing insect and mite species causing damage, frequency of occurrence, period of occurrence and attacked plant parts during two successive blooming and fruiting seasons. Thirteen insect and mite pests belonging to twelve families from orders Homoptera, Thysanoptera, Diptera, Coleoptera, Isoptera and Parasitiformes were recorded. The most dominant and economically important pests were a mealybug, *Planococcus ficus*, a scale insect, *Aonidiella aurantii*, an aphid, *Aphis gossypii*, and a psyllid, *Cacopsylla pyricola*. A stem borer, *Scolytus aegyptiacus*, and a mite, *Cenopalpus pulcher*, were present in high density. The less economically important pests were a mite, *Tetranychus urticae*, a scale insect, *Chrysomophalus ficus,* a thrips, *Thrips tabaci,* a leaf hopper*, Empoasca lybica,* a wax scale, *Ceroplastes floridensis,* a fruit fly *Ceratitis capitata,* and the termite *Anacanthotermes ochraceus. Mealybugs* were the most important and major insect pests that attack pear trees in the first season (2005), whereas in the second season (2006) Cacopsylla pyricola was the major pest. Temperatures and relative humidity showed a significant effect on the population of such pests.

Table (1): comparison between degree days and generation number of *P. operculella* under current and future climate (2050 and 2100) in El Behaira region

| No. of gradients | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Current climate | | Day | 81 | 44 | 29 | 27 | 26 | 24 | 27 | 29 | 36 | | | 36 |
| | | DDU | 464 | 464 | 472 | 465 | 471 | 464 | 466 | 467 | 463 | | | 466 |
| Future climate | 2050 | Day | 73 | 48 | 21 | 21 | 24 | 23 | 23 | 25 | 27 | 28 | | 32 |
| | | DDU | 460 | 463 | 468 | 466 | 466 | 465 | 460 | 467 | 474 | 468 | | 464 |
| | 2100 | Day | 64 | 50 | 23 | 19 | 24 | 22 | 22 | 23 | 25 | 26 | 29 | 31 |
| | | DDU | 464 | 465 | 475 | 466 | 476 | 462 | 466 | 469 | 472 | 462 | 466 | 468 |

Source: Abolmaaty *et al*, 2011

Table (2): comparison between degree days and generation number of *P. operculella* under current and future climate (2050 and 2100) in Ismalia region

| No. of gradients | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Current climate | | Day | 81 | 43 | 27 | 26 | 25 | 24 | 25 | 27 | 37 | 45 | | | 36 |
| | | DDU | 461 | 466 | 472 | 471 | 464 | 469 | 470 | 469 | 465 | 464 | | | 467 |
| Future climate | 2050 | Day | 65 | 47 | 24 | 20 | 24 | 22 | 22 | 23 | 26 | 26 | 34 | | 30 |
| | | DDU | 473 | 472 | 466 | 470 | 464 | 475 | 462 | 477 | 479 | 460 | 466 | | 471 |
| | 2100 | Day | 61 | 43 | 26 | 19 | 23 | 21 | 21 | 22 | 23 | 25 | 25 | 40 | 29 |
| | | DDU | 466 | 469 | 460 | 477 | 477 | 469 | 466 | 461 | 473 | 466 | 463 | 462 | 469 |

Source: Abolmaaty et al, 2011

Different species of family *Tephritidae* have been accidentally introduced into Egypt. Mediteranean fruit fly (Medfly), *Ceratitis capitata* (Wiedemann) was reported in Egypt early last century and ever since has been the serious pest of fruits. In 1990, the peach fruit fly, *Bactrocera zonata* (Saunders), although recorded in Egypt as early as 1924, has been recognize as causing fruit damage on a range of fruits including mango, guava, apricot, peach, apple and pear. Three seasons of field monitoring revealed a significantly higher abundance of *B. zonata* than of *C. capitata*, on all major fruit hosts in three different localities in Egypt. In laboratory comparisons, *B. zonata* manifested a higher threshold of temperature than *C. capitata*. The reduced survival rate of immature stages of *B. zonata* at 35°C was less acute than that observed for *C. capitata*. *B. zonata* immature stages survived 40°C while those of *C. capitata* failed to survive. *B. zonata* appeared to prefer warmer conditions and seemed well adaptable to hot climates (El Nagar *et al.*. 2010).

The seasonal abundance data suggested that the milder climate conditions in spring, autumn and early winter was favored by *C. capitata,*while extreme summer high temperatures supported survival of *B. zonata*. Both fruit fly species disappeared during extreme cold winter. This study concludes that *B. zonata* has gradually become so widely spread that it surpasses domination of *C. capitata* as the major fruit pest. It is possible that climate change is responsible for the appearance of *B. zonata* as a pest over the past 20 years, although the species was recorded in Egypt about 50 years earlier (El Nagar *et al.*. 2010).

# 5. Adaptation options

A wide variety of adaptive actions may be taken to lessen or overcome adverse effects of climate change on agriculture. At the level of farms, adjustments may include the introduction of later- maturing crop varieties or species, switching cropping sequences, sowing earlier, adjusting timing of field operations, conserving soil moisture through appropriate tillage methods, and improving irrigation efficiency. Some options such as switching crop varieties may be inexpensive while others, such as introducing irrigation (especially high-efficiency, water-conserving technologies), involve major investments (FAO, 2011).

Adaptation cannot be taken for granted: improvements in agriculture have always depended upon on the investment that is made in agricultural research and infrastructure. It would help to identify, through research, the specific ways that farmers now adapt to present variations in climate. Adaptations such as changing planting dates and choosing longer season varieties are likely to offset losses or further increase yields. The wide uncertainties in climate scenarios, regional variation in climate effects, and interactions of environment, economics, and farm policy suggest that there are no simple and widely applicable adaptation prescriptions. Farmers will need to adapt broadly to changing conditions in agriculture, of which changing climate is one factor. It is difficult to predict accurately what adaptations people will make. This is particularly challenge since adaptations are influenced by many factors, including government policy, technology research and development, and agricultural extension services.

Historically, farming systems have adapted to changing economic conditions, technology, and resource availabilities and have kept pace with a growing population. Evidence exists that agricultural innovation responds to economic incentives such as factor prices and can relocate geographically. A number of studies indicate that adaptation and adjustment will be important to limit losses or to take advantage of improving climatic conditions. Despite the successful historical record, questions arise with regard to whether the rate of change of climate and required adaptation would add significantly to the disruption likely due to future changes in economic conditions, technology and resource availabilities. If climate change is gradual, it may be a small factor that goes unnoticed by most farmers as they adjust to other more profound changes in agriculture stemming from new technology, increasing demand for food, and other environmental concerns such as pesticide use, water quality, and land preservation. However, some researchers see climate change as a significant addition to future stresses, where adapting to yet another stress such as climate change may be beyond the capability of the system. Part of the divergence in views may be due to different interpretations of adaptation, which include the prevention of loss, tolerating loss, or relocating to avoid loss. Moreover, while the technological potential to adapt may exist, the socioeconomic capability to adapt likely differs for different types of agricultural systems (Petzoldt Petzoldt and Seaman, 2008).

Important strategies for improving the ability of agriculture to respond to diverse demands and pressures, drawn from past efforts to transfer technology and provide assistance for agricultural development, include:

- Improved training and general education of populations dependent on agriculture, particularly in countries where education of rural workers is currently limited. Agronomic experts can provide guidance on possible strategies and technologies that may be effective. Farmers must evaluate and compare these options to find those appropriate to their needs and the circumstances of their farms.
- Identification of the present vulnerabilities of agricultural systems causes of resource degradation, and existing systems that are resilient and sustainable. Strategies that are effective in dealing with current climate variability and resource degradation also are likely to increase resilience and adaptability to future climate change.
- Agricultural research centers and experiment stations can examine the “robustness” of present farming systems (i.e., their resilience to extremes of heat, cold, frost, water shortage, pest damage, and other factors) and test the robustness of new farming strategies as they are developed to meet changes in climate, technology, prices, costs, and other factors.
- Interactive communication that brings research results to farmers and farmers’ problems, perspectives, and successes to researchers is an essential part of the agricultural research system.
- Agricultural research provides a foundation for adaptation. Genetic variability for most major crops is wide relative to projected climate change. Preservation and effective use of this genetic material would provide the basis for new variety development. Continually changing climate is likely to increase the value of networks of experiment stations that can share genetic material and research results.
- Food programs and other social security programs would provide insurance against local supply changes.

International famine and hunger programs need to be considered with respect to their adequacy.

- Transportation, distribution, and market integration provide the infrastructure to supply food during crop shortfalls that might be induced in some regions because of climate variability or worsening of agricultural conditions.
- Existing policies may limit efficient response to climate change. Changes in policies such as crop subsidy schemes, land tenure systems, water pricing and allocation, and international trade barriers could increase the adaptive capability of agriculture. Many of these strategies will be beneficial regardless of how or whether climate changes. Goals and objectives among countries and farmers vary considerably. Current climate conditions and likely future climates also vary. Building the capability to detect change and evaluate possible responses is fundamental to successful adaptation.

We believe that successive monitoring of the species and population changes in paddy fields is the priority need to be done than others. If the insects are key pests, then their population fluctuation, potential ability of damage and their relative biological and ecological characters have to be studied carefully, and then a control plan can be drew up, modified and set up finally. There are many measures can be used for curbing rice insect at present. The biological and physical controls are the well-known measures to most rice farmers, so as cultural practices and chemical spraying. However, each control method has its own virtues and defects, it is impossible to suppress the pests to an acceptable level by applying any control method alone. Therefore, a combination of more than one method to curb the population of insect pests below an economic threshold level has been suggested, the so-called “integrated control” or “integrated pest management”. The concept of integrated pest management is also adoptable in the case of climate change.

At present, the impacts of climate change on population dynamics and distribution of rice insect pests remain unpredictable. It is not easy to propose an appropriate tactic for controlling the insect pests in the future. However, based on experience and strategy of insect pest control used in tropical area, the integrated pest management approach seems feasible and applicable (FAO, 1995).

Farmers should keep in mind that climate change is likely to be a gradual process that will give them some opportunity to adapt. Although changes in our northeastern US climate are almost certainly happening, it is not precisely understood how these changes will affect crops, insects, diseases, and the relationships among them. If climate is warmer will increases in yield offset losses to pests, or will losses to pests outweigh yield advantages from warmer temperatures? It is likely that new pests will become established in more northerly areas and be able attack plants in new regions. It is likely that plants in some regions will be attacked more frequently by certain pests. A few pests may be less likely to attack crops as change occurs. It is likely that we will not know the actual impacts of climate change on pests until they occur. Clearly, it will be important for farmers to be aware of crop pest trends in their region and flexible in choosing both their management methods and in the crops they grow (Reilly et al, 1996).

Farmers who closely monitor the occurrence of pests in their fields and keep records of the severity, frequency, and cost of managing pests over time will be in a better position to make decisions about whether it remains economical to continue to grow a particular crop or use a certain pest management technique. If more fungicide or insecticide applications are required in order to successfully grow a particular crop, farmers will need to carefully evaluate whether growing that crop remains economical. Those farmers who make the best use of the basics of integrated pest management (IPM) such as field monitoring, pest forecasting, recordkeeping, and choosing economically and environmentally sound control measures will be most likely to be successful in dealing with the effects of climate change (**FAO**, 2011).

Sustainable land and water management combined with innovative agricultural technologies could mitigate climate change and help poor farmers adapt to its impacts. And new strategies must be built around 'green' agricultural technologies, such as adaptive plant breeding, pest forecasting, rainwater harvesting and fertilizer micro dosing, where small amounts of fertilizer are given to each seed.

Developing technologies to help farmers control pests is just as important. Climate change could have positive, negative or no impact on each pest. But we need better models to assess their global impact as most pest population prediction models have different spatial and temporal scales than global climate models.

Pests are usually controlled by cultural practices, natural enemies, host plant resistance, biopesticides and synthetic pesticides. But many of these control tactics are highly sensitive to the environment and climate change may render them less effective. It may alter the interactions between pests and their host plants, directly affecting resistance to pest control. For example, there are indications that stem rot (Sclerotium rolfsii) resistance in groundnut is temperature dependent, while in Kenya resistance to sorghum midge (Stenodiplosis sorghicola) breaks down under high humidity and moderate temperatures (World Bank, 2003; FAO, 2011).

We must urgently identify and develop crops that can resist pests under variable climates. Egypt is a country from the countries who are Parties to the UN Framework Convention on Climate Change have accepted certain commitments taking into account their common but differentiated responsibilities and other specific national and regional development priorities. The current status of the climate change awareness is an environment holds training courses for teachers and educational inspectors on how to simplify the climate change phenomenon for students, teaching them positive behaviors, with a group of ideas and teaching aids. Many public awareness programs were implemented "through audio & visual media means plus publishing series of books, posters and scientific articles in magazines on the phenomenon of climate change. There are now weekly environmental pages in several" national daily newspapers such as Al-Ahram, Al Gomhoria, and Al-Akhbar. There are several specialized T.V. and radio programs "address environmental problems and community participation in solving such problems. A number of training courses were given to journalists to help in shaping the thought of civil society towards activating policies and making decisions in this area.

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