Impact of Climate Change on Insect Pests

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ABSTRACT

The principal components of climate change are increased temperature and atmospheric carbon dioxide (CO_2) concentrations. Since climate change is believed to be more certain now, it is time for researchers to develop management strategies to cope with increased incidence of insect pests as a result of climate change. Of the several environmental factors temperature extremes play critical role in influencing the population of insect pests. Our experience indicated that there is a 'shift' in the pest status of several key species in recent periods, though these shifts may not be solely attributable to climate change. In the present situation, one can expect significant changes in the growth, development and population dynamics of various insect pests. The duration of the insect life cycle is altered under increased temperature and elevated CO_2 concentrations resulting in variable number of generations per year. Under elevated CO_2 higher consumption of foliage by leaf chewing insects with extended larval duration is observed in many studies. Published data reveals that some pests become more serious while others may decline. Evaluating the impact of climate change on insect pests is a very complex exercise and requires greater understanding of interactive factors. A more critical database on biotic stresses and their relationship with drivers of climate change is required for evolving adaptation strategies by farmers.

Key words: Climate change, temperature, carbon dioxide, insect pests.

INTRODUCTION

During the past 100 years the global average earth surface temperatures have increased by 0.6°C with 1990's being the warmest decade and 1998 the warmest year (Houghton *et al.*, 2001).The third Intergovernmental Panel for Climate Change (IPCC) report predicts that global-average surface temperature will increase further by 1.4-5.8°C by 2100 and atmospheric carbon dioxide (CO_2) to between 540 and 970 ppm over the same period. Climate change is likely to significantly affect agriculture by 2100 with wide variation in the estimates of impacts on crop yields across different regions. The principal drivers of climate change are increased temperature and carbon dioxide. These changes will have significant effect on growth of crops. Rise in temperature reduced the biomass and yields of various crops viz., rice, wheat and pulses. In contrary, elevated CO_2 enhanced photosynthesis, leaf area index, biomass and yields of various crops. As a principal source of carbon, it is very clear that changes in concentrations of carbon dioxide have marked effects on growth of crops. Temperature is identified as the dominant abiotic factor 'directly' affecting the insects. There is little evidence of any direct effects of CO_2 on insects and mostly the impact of elevated CO_2 is mediated through host crop, particularly in case of herbivorous or phytophagous insects. Effects of climate change on insect herbivores can be direct (temperature), through impacts on their physiology and behaviour, or indirect, where the insects respond to climate-induced changes mediated through other factors, such as host plant induced growth changes.

The information on effect of increased temperature and CO_2 concentrations on biology and ecology of insect pests was synthesized (Coviella and Trumble, 1999; Hunter, 2001 and Bale *et al.*, 2002). The present paper shares the information on the direct effects of climate change on insect pests available through literature and the experiences of CRIDA and ICRISAT research in the recent past.

Effect of temperature on insect population

Weather and its significant interaction with key pests of several crops is well known among researchers and farming community. However, so far this concept has not been applied in plant protection to minimize the ongoing injudicious use of pesticides. The present day plant protection is mostly concentrated on chemical control and leads to the presence of residues in food and fodder and feed. Pest surveillance and monitoring in relation to weather can considerably reduce the case of chemicals. In order to fine tune the existing pest predictions, understanding the thermal requirements and degree days for key pest and their associated natural enemies are of prime importance.

Groundnut leafminer (GLM**)**, *Aproaerema modicella* is the key pest of groundnut in many parts of India particularly the southern states and some other Asian countries. This pest is favored by the hot dry conditions of the post-rainy season. The life cycle is completed in 21-28 days and this species completes 3-4 generations in a crop season in south India. Fluctuations are regulated by abiotic and biotic factors. Heavy persistent rains, high relative humidity (RH) and low temperatures reduce pest numbers, where as dry weather, bright sunshine and occasional rains favor pest buildup (Ghule *et al*., 1989). In Bangladesh and India, the densest populations of GLM occur at the end of the post-rainy season, March-April (Amin and Mohammad, 1980; Islam *et al*., 1983)**.** GLM is often a problem towards the end of the rainy season (September and October), especially in drought or low-rainfall years (Amin, 1983). GLM populations fluctuate widely between seasons. Reliable and quantifiable data are specifically needed on the effects of temperature, rainfall and relative humidity on GLM population dynamics. Amin (1987) and Khan and Raodeo (1987) have suggested that high rainfall reduces leafminer populations even though data from the latter do not support this conclusion. They observed high populations in August September during a high rainfall period and populations declined in March when no rain was recorded (Khan and Raodeo, 1987).

Reduction in the GLM populations depends upon the insect pest stage and the prevailing weather i.e., during rainy season with heavy rainfall it is likely that adults are easily washed away by rain resulting in reduced incidence of GLM. Several authors have suggested that rainfall may reduce GLM larval populations in some seasons and have tried to correlate high GLM numbers with low rainfall seasons. If rainfall were an important larval mortality factor, then GLM populations should be higher in post-rainy season. This conflicting patterns of rainfall and GLM abundance point out the difficulty of using single factor to explain biological phenomena. It is likely that rainfall may indirectly influence GLM populations by increasing humidity which will favour GLM pathogens. Temperature was also positively correlated with GLM incidence and accounted for more of the variation than rainfall (Lewin *et a*l., 1979). Logiswaran and Mohanasundaram (1986) noted negative associations of light-trap catches with maximum and minimum temperatures and wind speed, and positive relationships with total rainfall and morning evening relative humidity.

Tobacco caterpillar, *Spodoptera litura* is widely distributed throughout Asia and Oceania and is highly polyphagous in nature. There is pronounced peak in the flight activity of moths (adults) during late January and early February that indicates that crops sown after mid-January are prone to pest attack in the east coastal belt of India. The only other factor of applied importance is migration. Clearly, the number of adult females visiting the crop will influence the egg density and the larval density. ICRISAT in collaboration with NARS and other mentor organizations developed, evaluated and shared an effective monitoring systems using pheromones for key insect pests of groundnut. Several groundnut pests recorded zero developmental rates around 10°C. However, *Spodoptera litura* and *Helicoverpa armigera*, developmental thresholds were above the mean winter temperature (<10°C) and emerged as usual in the spring in Southern states of India. A possible increase in the number of generations per year was not clearly shown by the trap capture records (Shanower, *et a*l., 1995 and Ranga Rao, *et al.*, 1989).

Helicoverpa armigera is one of the widely distributed crop pests throughout Asia, Australia, New Zealand, Africa southern Europe and many Pacific islands (Zalucki *et al*., 1986). Frequent outbreaks of this species are common in India on several crops. Generally the females prefer to oviposit on the reproductive parts of the plant (flowers and fruits) in a normal situation. Considerable progress had been made in modeling population outbreaks of this species in Australia and USA. Studies in India in the past two decades revealed simple eco-friendly predictions in farmers fields mainly based on the cumulative rainfall in rainy and post rainy seasons (Trivedi *et al.,* 2004).

Pest surveillance data generated at ICRISAT on key groundnut pests for the past 10 years has been summarized and subject analysis against various abiotic factors such as rainfall, minimum and maximum temperatures and relative humidity (%). The standard week-wise pheromone trap catches and larval population of *Spodoptera* and groundnut leafminer, were correlated with the above abiotic factors. The analysis brought out interesting results with no relationship of maximum temperature and relative humidity on the adult catches and adult populations, irrespective of pooling data, standard week or monthly or yearly. The negative effect of rainfall on *Spodoptera* adult catches and larval populations was very clear through correlation of the data at standard week level and monthly level. But, cumulative yearly rainfall data has not shown any relationship either adult catch or pest incidence in the field. These results clearly indicated high negative correlation of rain fall and adult catch with standard week-wise data set and the correlation efficiency decreased as one approached monthly data and further (Table 1).

Table 1: Correlation between *Spodoptera* larval population in groundnut and adult populations monitored by pheromone trap with weather parameters.

Variables	**Standard week data**		**Monthly data**		**Yearly data**	
	Larvae plant^{-1}	**Adult catches trap^{-1}**	**Larvae plant^{-1}**	**Adult catches trap^{-1}**	**Larvae plant^{-1}**	**Adult catches trap^{-1}**
Larvae plant^{-1}	-	✓+	-	✓+	-	X
Adult catches trap^{-1}	✓+	-	✓+	-	X	-
Rainfall (mm)	✓-	✓-	✓-	✓-	X	X
Minimum Temp °c	✓-	✓-	✓-	X	X	X
Maximum Temp °c	X	X	X	X	X	X
Relative humidity (%)	X	X	X	X	X	X

✓+: Significant positive correlation, ✓- : Significant negative correlation, X: No correlation

In case of leafminer, all the abiotic factors except minimum temperature and its relation to larval population have not shown any relationship either with adult catch or larval population in the field. However, trap catches have shown strong correlation with larval population but the relationship between these two parameters was shown positive irrespective of pooling of data. Thus, the study revealed the implications of looking at yearly and monthly data than weekly data. The data also tells us the need for more refined data such as daily weather and its relation to adult or larval or egg load rather than cumulative effect of weekly information (Table 2). Hence, it is necessary to produce such a refined data on key species of various crops in order to develop effective pest forecasting systems.

Table 2. Correlation between groundnut leafminer larval population and adult populations monitored by pheromone trap with weather parameters.

Variables	**Standard week data**		**Monthly data**		**Yearly data**	
	Larvae plant^{-1}	**Adult catches trap^{-1}**	**Larvae plant^{-1}**	**Adult catches trap^{-1}**	**Larvae plant^{-1}**	**Adult catches trap^{-1}**
Larvae plant^{-1}	-	✓+	-	✓+	-	✓+
Adult catches trap^{-1}	✓+	-	✓+	-	✓+	-
Rainfall (mm)	X	X	X	X	X	X
Minimum Temp °c	✓+	X	X	X	X	X
Maximum Temp °c	X	X	X	X	X	X
Relative humidity (%)	X	X	X	X	X	X

✓+: Significant positive correlation, ✓- : Significant negative correlation, X: No correlation

The information on various egg and larval parasites of leaf miner and *Spodoptera* over 10 years clearly indicated any deleterious effects of environmental factors on these natural enemies. In case of *Spodoptera*, the mean incidence of larval parasitism over 7 years (1985-1991) was 15.1% in rainy season (June-September) compared to 9.8% in the post rainy season (November – February). Similar trend was also noticed in case of groundnut leaf miner during 1984 – 1993 showing mean larval parasitation of 34% in rainy season compared to 40% in post-rainy season, emphasizing no environmental influence on these parasitic fauna.

The general consensus is that extremes of temperature will become more common, with an overall warming trend. In this situation one can expect significant changes in the population trends of various insect pests as experienced at ICRISAT Patancheru location (Table 3).The status of the majority of the pests was shifted over time. Though, the observed pest shifts may not be solely attributable to climate change, the impact of climate change on their status can be observed clearly.

Table 3. Trends in the Pest status of economically important Insect species over the past three decades at ICRISAT Patancheru location (1978-2009).

Insect species	**Status**	
	1978	**2009**
Helicoverpa armigera	+	+
Spodoptera litura	+	+
Aproaerema modicella	+	-
Holotrichia serrata	+	-
Amsacta albistriga	+	-
Maruca vitrata	-	+
Melanagromyza obtusa	-	+
Caryedon serratus	-	+
Pseudococcus corymbatus	-	+
Aphis craccivora	-	-
Thrips palmi (as vector)	-	+

+ = Important; - = Not important

Increased temperature

Temperature is identified as dominant abiotic factor directly affecting the insects. It has significant effects on populations of insects affecting their development, reproduction and dispersal which have been expressed in changes in pest activity and abundance. Species with a 'large geographical range' will tend to be less affected. Several observations can be made from literature on influence of elevated temperature on insect growth and development.

1. Increased temperature influenced the larval development and fecundity of *O.brumata* insects (Dury *et al.*, 1998) and long term exposure to increased temperature 3.5^{0}C shortened the insect development (Williams *et al.,* 2003).The temperature enhancement increased the relative growth rate of chrysomelid beetles (Veteli *et al.,* 2002)
2. Increased temperatures can potentially affect the insect survival, development and population size. Insects proliferate more readily in warmer climate, since conditions for growth and multiplication is more favorable compared to cooler conditions. Thus incidence of insect pests will be more in the areas with increased temperature conditions.
3. Because of warm winter and spring, many aphid species started their spring migration much earlier than 'normal' and the peach-potato aphid (*Myzus persicae*), in particular, has been captured in unprecedented numbers in the traps.
4. The rate at which most pests develop is dependent on temperature and every species has a particular 'threshold temperature' above which development can occur, and below which development ceases. As temperature rise, some pest species may be able to complete more generations in a year. This effect may be most noticeable in insects with short life-cycles such as aphids and the diamond-back moth. On

the other hand, the temporary exposure of populations to extremely high temperatures may delay the development of surviving individuals and thus delay the subsequent generation.

5. Warmer winter temperatures may allow larvae to survive the winter where they are limited by the cold. Thus greater infestation is expected in those areas.
7. Climate change may affect our ability to control pests. For example, high temperature is reported to reduce the effectiveness of some pesticides. If pests are able to complete more generations in a season then this may lead to greater pesticide use
8. More no of application of pesticide use which in turn may lead to the more rapid development of pesticide resistance. Strategies to avoid the development of resistance need to be planned in advance and rely on the availability of a range of pesticides and/or alternative control methods.

In addition to the above observations some more predictions and generalizations were made by several researchers and are given in the table.

Table 4: Impact of increased temperature on insects

Anticipated /Expected effect	**References**
Under climate change scenario increased asynchrony between host plant and insect herbivore, with obvious adverse consequences.	Dewer and Watt 1992
Higher temperatures keeping all other variables equal, allow faster development of insects and may allow for additional generations of insects within a year.	Pollard and Yates, 1993
Climatic warming will allow the majority of 'temperate' insect species to extend their ranges to higher latitudes and altitudes.	Gaston and Williams, 1996
Expand their geographical ranges to higher latitudes and altitudes, as has already been observed in a number of common butterfly species.	Parmesan *et al*., 1999
Elevated temperature is known to alter the phyto-chemistry of the host plants and affect the insect growth and development directly or indirectly through effect on host plants.	Williams *et al* ., 2000
Diversity of insect herbivores and the intensity of herbivory increases with rising temperatures at constant latitude. Individuals may develop faster at higher temperature and survival may even be enhanced, but these insects may consequently have lower adult weight and fecundity.	Bale *et al*., 2002

Predicting insect response to increased temperature is largely based on field and laboratory studies carried out either on single species or combination of species. These predictions of insect population dynamics are complex even at the level of single individual level as life cycles are dependent on both biotic and abiotic factors.

Effect of Elevated CO_2 on insect population

Generally the impact of carbon dioxide (CO_2) on insects is observed to be 'indirect' – impact on insect growth and development resulting from change in the host crop. Elevated atmospheric CO_2 expected in the near future as a consequence of increasing emissions will alter the quantity and quality of plant foliage, which in turn can influence the growth and development of insect herbivores. The impact of elevated CO_2 on the phytochemistry of the plants was well documented (Coviella,Trumble, 1998 and Hunter, 2001).

The atmospheric CO_2 concentrations have increased by above 20% and elevated CO_2 effects the plant growth and range of physical and chemical characteristics of the plant/crop. These include reduction in the leaf nitrogen content, changes in the defense compounds, water content, carbohydrates and leaf thickness. Indications are that exposure to elevated CO_2 levels will increase the plant photosynthesis, growth, above ground biomass, leaf area, yield, carbon and C:N ratio. These changes can influence the food quality for herbivorous insects and was well reviewed (Hunter, 2001). These changes in the leaf quality are likely to have varied effect on the performance of insect herbivores. The information on effect of elevated CO_2 on insect pests was compiled and presented by Srinivasa Rao *et al., (*2008).

Succinctly the information revealed that the performance of the same insect varied from host to host-indicating host species specificity. Published data on impact of elevated CO_2 on insect pests indicated a general decrease in foliar nitrogen concentration and increase in carbohydrate and phenolic based secondary metabolites (Bezemer and Jones, 1998 and Whittaker, 1999). The consumption by herbivores was related primarily to changes in nitrogen and carbohydrate levels. The leaf-mining insects could only partially compensate by increased consumption and pupal weights did decline. The phloem-feeding and whole-cell-feeding insects responded positively to elevated CO_2, with increases in population size and decreases in development time.

Experimental findings from CRIDA

Several experiments were conducted using open top chamber (OTC) facility to study the impact of elevated CO_2 levels on insects. Three square type open top chambers (OTC) of 4x4x4 m size were constructed at CRIDA, Hyderabad, two for maintaining elevated CO_2 concentrations of 700±25 ppm CO_2 and 550±25 ppm CO_2 and one for ambient CO_2. An automatic CO_2 enrichment technology was developed by adapting software SCADA to accurately maintain the desired levels of CO_2 inside the OTCs. The concentration of CO_2 in the chambers was monitored by a non-dispersive infrared (NDIR) gas analyzer.

Castor, groundnut plants were grown in the three OTCs and also in the open, outside the OTCs. The concentration of CO_2 in the atmosphere (ambient) was taken as 350±25 ppm. Thus, crops were maintained under 4 CO_2 conditions; 700±25 ppm CO_2 inside OTC (700 CO_2), 550±25 ppm CO_2 inside OTC (550 CO_2), ambient CO_2 inside OTC (350 CO_2 OTC) and ambient CO_2 in the open (350 CO_2 open). Various experimental trials were conducted using the foliage obtained from the crops grown under different OTC's.

To understand the nutritional quality of foliage bio chemical analysis was conducted. Biochemical analysis of leaf samples indicated that the leaf nitrogen content was distinctly lower in elevated CO_2 foliage. In contrast, carbon content was higher in elevated CO_2 foliage. Consequently, the change in the relative proportion of carbon to nitrogen (C:N ratio) was considerably higher in elevated CO_2 foliage. Elevated CO_2 foliage had higher polyphenol content too, compared to ambient CO_2.

Larval growth performance

Larval duration or time from hatching to pupation in larvae of both the species was significantly influenced by the CO_2 condition under which leaves offered to them were produced. Larval duration for both larvae was extended by about two days when fed with elevated CO_2 foliage (Fig. 1). Larval dry weights measured during the feeding period differed significantly among CO_2 conditions .Larvae ingested significantly higher quantity of elevated CO_2 foliage compared to ambient CO_2 foliage. For instance, *A. janata* consumed 62.6% more of 700 CO_2 foliage than 350 CO_2 chamber foliage. The rate of consumption (RCR) was also higher in case of elevated CO_2 foliage. Thus, larvae fed with elevated CO_2 foliage consumed more each day and over a longer period, resulting in considerably increased ingestion. Larval weights prior to pupation were also significantly affected by the foliage offered, being higher with elevated CO_2 foliage, but differences in larval weight were not as marked as differences in the amount of leaf ingested. Larval growth rates (RGR) were significantly lower with elevated CO_2 foliage in case of *A. janata*, while in case of *S. litura*, the differences were not significant (Srinivasa Rao *et al*., 2009).

The efficiency with which ingested food was converted into body mass was lower with elevated CO_2 foliage in case of *A. janata*, but in *S. litura*, there were no significant differences. The efficiency of conversion of digested food into body mass (ECD) was lower with elevated CO_2 foliage for both species of larvae. The digestibility (AD) of elevated CO_2 foliage was significantly higher than ambient CO_2 foliage for both the species, more so in case of *S. litura.*

The data of larval weight were fitted to a compound growth function of the form $y = ax^b$, where 'y' is larval weight in mg, 'x' is time in days, 'a' is a constant and 'b', 'a' coefficient that indicates the growth rate. Differences in growth rates of *S. litura*, which were not visible from relative growth rate calculations, became clear with the growth functions. The daily growth rates of *S. litura* were considerably lower with elevated CO_2 foliage .While the daily growth rate was 30.99% with 350 CO_2 foliage, it was just 18.53% with 550 CO_2 foliage. In *A. janata* also, the daily growth rates were markedly lower with elevated CO_2.

Relationship of larval performance with leaf biochemical parameters was worked out. Biochemical constituent(s) of the leaf influenced larval consumption and growth. Leaf consumption and larval weights were positively and significantly correlated with leaf carbon, polyphenols and C:N ratio, and negatively (-0.804 to -0.834) with leaf nitrogen content. The consumption and weight gain of the larvae were negatively and significantly influenced by leaf nitrogen, which was found to be the most important factor affecting consumption and growth of larvae.

Similarly the consumption pattern and growth of *Spodoptera litura* on groundnut also significantly varied across CO_2 concentrations. The insect performance indices were significantly affected. The 700 and 550 ppm CO_2 foliage was more digestible with higher values of approximate digestibility. The relative consumption rate of larvae increased whereas the efficiency parameters; efficiency of conversion of ingested food (ECI), efficiency of conversion of digested food (ECD), and relative growth rate (RGR) decreased in case of larvae grown on 700 and 550 ppm CO_2 foliage.

Impact of elevated CO_2 on natural enemies

Limited studies are available in the literature on impact of elevated CO_2 on natural enemies at third trophic level. The growth and development of insect herbivores varied with the nutrition quality of their diet (host plant) and the dietary differences showed varied effects on parasitoids. The population size of the insects significantly differed under elevated CO_2 and in turn influencing the insect fecundity. Thus, any dietary differences that prolong developmental time, increase food consumption, and reduce growth by herbivores serve to increase the susceptibility of herbivores to natural enemies (Roth & Lindroth, 1995). On the other hand, poor host nutrition could also decrease parasitoid fitness. Few studies explored the impact of elevated CO_2 on natural enemies (parasitoids and Predators) at third trophic level (Bezemer *et al*., 1999; Stacey and Fellowes, 2002).

Chen *et al*., 2005 showed that increasing CO_2 concentrations could alter the preference of lady beetle to aphid prey and enhance the biological control of aphids by lady beetle in cotton crop. This study provided the first empirical evidence that changes in prey reared on host plant grown at different levels of CO_2 altered the feeding preferences of the predator.

Discussion and Conclusions

Insects are critical to agriculture in several ways since they perform vital services such as breaking down organic matter, pollinating flowers. On the other hand they are also destructive to crops and vectors for several plant and animal diseases. However, it is a well known fact that climate variations bound to influence insects, both insects are also known for their quick adaptation for changing environments. Climate variability affects insects directly and also indirectly, through their change in physiology, population turnover, host plants and migratory responses.

There are still many unknowns in the climate change influencing the insect pests. The general consensus is that extremes of temperature will become more common. In this situation one can expect significant changes in the population trends of various insect pests as experienced at ICRISAT Patancheru location. Our experience at ICRISAT clearly brought out shift in the pest status of several key species over the past three decades. Similarly, an increase in the number of generations can translate into the need for additional controls and would present more challenges of management.

The quantification of the impact of climate variability can be achieved through the adoption of well proven and innovative tools that allow the development of integrated pest management strategies designed for target areas. With increasing ability, reliability of the effective IPM strategies, the decision makers involved in plant protection should consider short medium and long term approaches such as:

1. Decision support frame work to provide medium term strategies addressing temporal and spatial distribution of insect pests and their natural enemies in terms of climatic variability and their impact on the profitability and innovative agricultural practices.
2. Short term seasonal climate forecasting to enable farmers and other stakeholders to fine tune medium term strategies for effective management of variable weather.
3. Long term information on the extent of climate change and its impact on agriculture and the implications on crop productivity / pest management.

Increased temperature would reduce crop duration and causes the change in the growth and development of the insect pests. The duration of the insect life cycle gets reduced under increased temperature resulting in more number of generations per year. Under elevated CO_2 conditions, higher consumption of foliage by leaf chewing insects with extended larval duration is predicted in majority cases. The studies that combine the effects of elevated CO_2 (enriched plants) and increased temperatures on insect performance are rare. The documented information reveals that some pests become more serious while others may decline. The impact of increased temperature and elevated CO_2 on crop and insect herbivore interactions is still unknown as both these variables are counteracting.

However, complex interactions among temperature, host plant quality, and insect performance make pest predictions more complicated. For example, the reduced rates of insect growth that have been observed under elevated CO_2 may be masked by increased temperatures. There is need to have long-term, multifactorial experiments under field conditions to study the interactive and confounding effects of elevated CO_2, temperature and other ecological variables on the insects.

In the present day plant protection though there are effective technologies available in suppressing the pests but proper monitoring and forecasting systems are not in place. Though, the knowledge base is available on the above areas in various fields the information is highly scattered. Hence, there is an urgent need to bring them under single umbrella for better organizing these activities. With the advancement and the availability of the experts in various fields, it is time to put the existing information together to develop efficient and affordable models for key pests and diseases.

To arrive at concrete conclusions in developing sustainable eco-friendly plant protection approaches, evaluation of long term historic data on insect pests need to be examined thoroughly with the involvement of multi-organizational expertise. It must include adaptation and mitigation strategies, more investments in agricultural research and extension, rural infrastructure to ensure the development of resilient and healthy ecosystems.

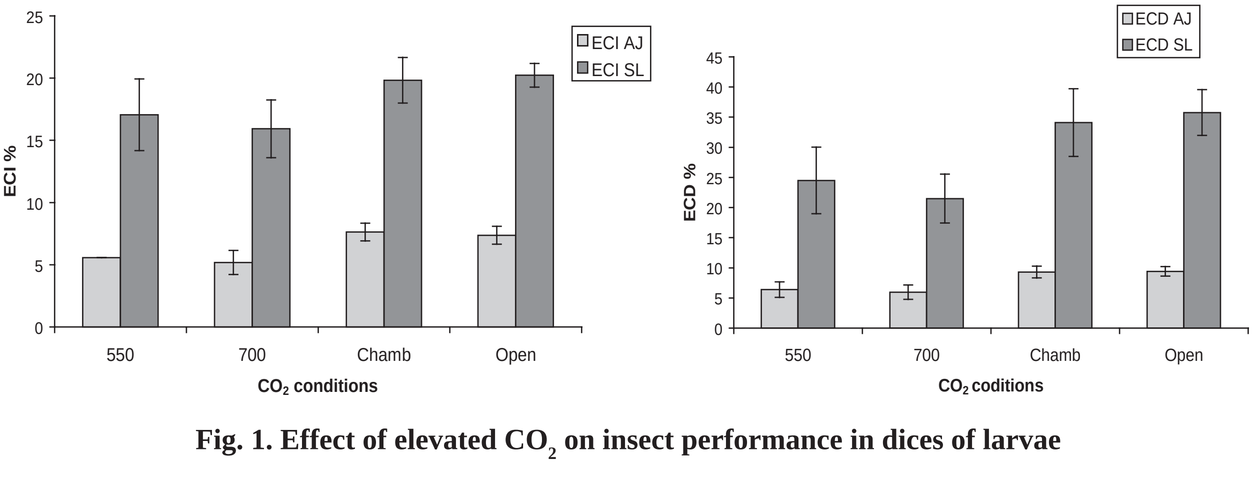

Fig. 1. Effect of elevated CO_2 on insect performance in dices of larvae

REFERENCES

Amin, P.W. 1983 Major field insect pests of groundnut in India and associated crop losses. Special issue *Indian J. Entomol*. 2:337-344.

Amin, P.W. 1987 Insect pests of groundnut in India and their management. In; Plant protection in field crops Ed. by M. Veerabhadra Rao, and S. Sithanantham, pp. 219-233: Plant protection Association of India Hyderabad.

Amin, P.W. and Mohammad, A.B. 1980 Groundnut pest research at ICRISAT. In: Proceedings of the International Workshop on Groundnuts. Pp.158-166, ICRISAT, Patancheru, AP 502 324, India.

Bale, Jeffery S., Gregory J. Masters, Ian D. Hodkinson, Caroline Awmack, T. Martijn Bezemer, Valeriek. Brown, Jennifer Butterfield, Alan Buse, John C. Coulson, John Farrar, John E.G. Good, Richard Harrington, Susane Hartley, T. Hefin Jones, Richard L. Lindroth, Malcolm C. Press, Ilias Symrnioudis, Allan D. Watt and John B. Whittaker, 2002. Herbivory in global climate change research: Direct effects of rising temperature on insect herbivores, *Global Change Biology* 8, 1-16.

Bezemer T.M. and Jones T.H. 1998. Plant-insect herbivore interactions in elevated atmospheric CO_2; quantitative analyses and guild effects. Oikos 82: 212-222.

Bezemer, T.M., and T.H. Jones, and K.J. Knight. 1999. Long-term effects of elevated CO_2 and temperature on populations of peach aphid *Myzus persicae* and its parasitoid *Aphidium matricariae*. *Oecologia* (Berl.). 116: 128-135.

Bezemer, T.M., Knight, K.J., Newington, J.E. and Jones T.H. 1999. How general are aphid responses to elevated atmospheric CO_2? *Ecology and Population Biology* 92(5): 724-730.

Chen, F., Ge, F and Parajulee, M.N. 2005. Impact of Elevated CO_2 on Tri-Trophic Interaction of *Gossypium hirsutum*, *Aphis gossypii*, and *Leis axyridis*. *Environmental Entomology*. 34(1): 37-46.

Coviella and Trumble 1998. Effects of elevated atmospheric carbon dioxide on insect-plant interactions, *Conservation Biology*. 700-712.

Dewer RC,and Watt AD 1992. Predicted changes in the synchrony of larval emergence and budburst under climatic warming. *Oecologia*, 89, 557-559.

Dury, S.J., Good, J.E.G., Perrins, C.M., Buse, A. and Kaye, T. 1998. The effects of increasing CO_2 and temperature on oak leaf palatability and the implications for herbivorous insects. *Global Change Biology* 4: 55-61.

Gaston KJ and Williams PH 1996. Spatial patterns in taxonomic diversity. In: *Biodiversity* (ed: Gaston KJ), pp. 202-229. Blackwell Science, Oxford.

Ghule, B.D., Jagtap, A.B., Dhumal, V.S. and Deokar, A.B. 1989 Influence of weather factors on the incidence of leaf miner (*Aproaerema modicella* Deventer) on groundnut. *Journal of oil seeds Research* 6, 17-21.

Houghton JT, Ding Y, Griggs DJ, Noquer M, Van der Linden PJ and Xiaosu D 2001 Climate change 2001: The scientific basis. Cambridge University Press, Cambridge pp-944.

Hunter, M.D. 2001. Effects of elevated atmospheric carbon dioxide on insect-plant interactions. *Agricultural Forest Entomology*. 3, 153-159.

Islam, W., Ahemad, K.N., Nargis, A. and Islam, U. 1983 Occurrence, abundance and extent of damage caused by insect pests of groundnuts (*Arachis hypogaea*). *Malasian Agric. J.* 54: 18-24.

Khan, M.I. and Raodeo, A.K. 1987. Seasonal incidence of groundnut leaf miner, *Aproaerema modicella* Deventer (Lepidoptera: Gelechiidae). Punjabrao Kroshi Vidyapeeth Res. J. 11:93-96.

Lewin, H.D., Saroja, R., Leela David, A. and Padmanabhan, M.D. 1979 Influence of sowing time and weather on the incidence of groundnut leaf miner. *Indian J. Agric. Sci.* 49:886-891.

Logiswaran, G. and Mohanasundaram, M. 1986 Influence of weather factors on the catches of moths of groundnut leaf miner (*Aproaerema modicella* Deventer) in the light trap. *Entomon* 12:147-150.

Parmesan C, Ryrholm N, Stefanescu C, Hill JK, Thomas CD, Descimon H, Huntley B, Kaila L, Kulberg J, Tammaru T, Tennent WJ, Thomas JA and Warren M 1999. Poleward shifts in geographical ranges of butterfly species associated with regional warming, *Nature*, 399, 579-583.

Pollard E and Yates TJ 1993 Monitoring Butterflies for Ecology and Conservation. Chapman & Hall, London.

Ranga Rao, G.V., Wightman, J.A. and Ranga Rao, D.V. 1989 Threshold temperatures and thermal requirements for the development of *Spodoptera litura* (Lepidoptera: Noctuidae). *Environmental Entomology*, 18(4): 548-551.

Roth, S.K., and Lindroth, R.L. 1995 Elevated atmospheric CO_2: Effects on photochemistry, insect performance and insect-parasitoid interactions. *Global Change Biology* 1: 173-182.

Shanower, T.G., Gutierrez, A.P. and Wightman, J.A. 1995 Effect of simulated rainfall on eggs and larvae of the groundnut leaf miner, *Aproaerema modicella.* International-Arachis-Newsletter. 1995, No. 15, 55-56.

Srinivasa Rao, M, Srinivas, K, Vanaja, M., Rao, GGSN. Venkateswarlu, B and Ramakrishna, YS 2009 Host plant (*Ricinus communis* Linn) mediated effects of elevated CO_2 on growth performance of two insect folivores *Current Science.* 97(7):1047-1054.

Srinivasa Rao, M., Srinivas, K., Vanaja M, Rao GGSN and Venkateswarlu B.2008 Impact of elevated CO_2 on insect herbivore-host interactions. *Research Bulletin*. Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad India. pp 36.

Stacey, D.A., and M.E. Fellowes. 2002. Influence of elevated CO_2 on interspecific interactions at higher trophic levels. *Global Change Biology*. 8: 668-678.

Trivedi, T.P., Yadav, C.P., Vishwadhar, Srivastava, C.P., Dhandapani, A., Das, D.K. and Joginder Singh. 2004 Monitoring and Forecasting of *Heliothis/Helicoverpa* populations. Pages 119-140 in Sharma, H.C., (ed), *Heliothis/ Helicoverpa* Management: Emerging Trends and Strategies for Future Research.

Veteli TO, Kuokkanen K, Julkunen-Tiitto R, Roininen, H. and Tahvanainen J. 2002 Effects of elevated CO_2 and temperature on plant growth and herbivore defensive chemistry. *Global Change Biology* 8(12): 1240-1252.

Whittaker, J.B. 1999. Impacts and responses at population level of herbivores insects to elevated CO_2. *European Journal Entomology* 96: 149-156.

Williams, R.S., Lincoln, D.E. and Norby, R.J. 2003 Development of gypsy moth larvae feeding on red maple saplings at elevated CO_2 and temperature. *Oecologia* 137: 114-122.

Williams, R.S., Norby, R.J. and Lincoln, D.E. 2000. Effects of elevated CO_2 and temperature-grown red and sugar maple on gypsy moth performance. *Global Change Biology* 6: 685-695

Zalucki, M.P., Daglish, G., Firempong, S. and Twine, P. 1986. The biology and ecology of *Heliothis armigera* (Hubner) and *H. punctigera* Wallengren (Lepidoptera: Noctuidae) in Australia: What do we know? *Australian Journal of Zoology* 34: 779-814.