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CTGC: A facility to study the interactive effects of CO_2 and Temperature

M. Srinivasa Rao, M. Vanaja, I. Srinivas, C.V.K. Nageshwara Rao, K. Srinivas, M. Maheswari, M. Prabhakar, P. Sreelakshmi, S. Bhaskar and K. Sammi Reddy

National Innovations in Climate Resilient Agriculture (NICRA)
ICAR-Central Research Institute for Dryland Agriculture
Hyderabad – 500 059

Raising of Crops in Chamber

Preparatory cultivation

Sowing

Irrigation by sprinklers

Initial stage of crop

Inter cultivation

Foggers in action

Crop stand

Harvested crop

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किसानों का हमसफर
भारतीय कृषि अनुसंधान परिषद
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National Innovations in Climate Resilient Agriculture (NICRA)
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Acknowledgements

The major objective of National Innovations in Climate Resilient Agriculture (NICRA) project is to enhance the resilience of Indian agriculture, covering the crops, livestock and fisheries to climatic variability and climate change through development and application of improved production and risk management technologies. The first and foremost activity addressed in the project was establishment of state of the art research facilities to better understand the climate change induced impacts on behaviour of crop, insect pests, livestock and fisheries etc. Several unique research facilities were established in NICRA project and among these, CTGC (Carbon dioxide and Temperature Gradient Chambers) is the one major facility which is first of its kind. The establishment of CTGC facility is complex in nature which involves commissioning and integration of various components of the facility. This effort received strong support and guidance from Dr. A.K. Singh and Dr. A.K. Sikka, former Deputy Directors General (NRM), and Dr. K. Alagusundaram, current Deputy Director General (NRM), ICAR, New Delhi. Dr. B. Venkateswarlu, former Director ICAR-CRIDA, is instrumental in getting this state of art facility initiated and the effort was subsequently supported by Dr. Ch. Srinivasa Rao, Director, ICAR-NAARM. The facility was established under the guidance and supervision of technical committee comprising of Drs G. Korwar, C. Thyagaraj and K.L. Sharma who served as chairmen of the committee along with some of the authors of this document, the Chief Administrative Officer, Senior Finance and Accounts Officer and Principal Scientist, Indian Institute of Chemical Technology, Hyderabad as an external member. Authors are thankful to each one of them.

Acknowledgements

CTGC: A facility to study the interactive effects of CO_2 and Temperature

1. Introduction

Global Mean Surface Temperature (GMST) and Global atmospheric CO_2 concentrations have been increasing at a significant rate since last 19th century. The increase in temperature between the average of the 1850-1990 period and the 2003-2012 period is 0.78°C (0.72 to 0.85°C), based on the single longest dataset available. The increase in the amount of CO_2 in the atmosphere will be by about 40% when compared with pre-industrial levels (IPCC, 2013). Increase in temperature (*e*Temp) and elevated CO_2 (*e*CO_2) influence crop growth significantly and in turn affect the insect herbivores both directly and indirectly. Though it is known that the increase in temperature will have a greater effect on insects than the rising CO_2 concentration (Harrington *et al.*, 2001), the interactive and combinational effect of both parameters is more evident.

Climatic models predict 1.7-4.9°C increase in mean global temperature from 1990 to 2100. Climatic variability together with increase in atmospheric carbon dioxide and temperature has lot of implications in agriculture sector. Climate change affects agriculture through changes in (i) Average temperatures, rainfall, and climate extremes (e.g., heat and cold waves), (ii) Insect pests and diseases, (iii) Atmospheric CO_2 and ground-level ozone concentrations, (iv) Nutritional quality of foods and (v) Increased sea levels (Hoffmann, 2013). Climate change could increase the risk of food insecurity for poor and vulnerable groups. The impact of climate change on agriculture could result in problems of food and livelihood securities of much of the agrarian population. Climate change can affect crop yields (both positively and negatively) and alter the type of crops that can be grown in certain areas by impacting natural resources such as water for irrigation and amount of solar radiation that affect plant growth besides influencing the prevalence of pests on crops.

The impact of elevate CO_2 and temperature was studied independently and individually by using various facilities. The advantage of these facilities is to capture the effects of both CO_2 and temperature separately. The information about these facilities is given here under.

2. CO_2 / Temperature related facilities

2.1 Temperature Gradient Tunnel (TGT)

Temperature gradient tunnels (TGT) are used to provide near to ambient conditions and conditions simulating predicted increases in temperature. Generally, the dimensions of TGT are 15 to 50 meters (Length). Sophisticated air blowing/heating facilities for achieving different gradient of 1 to 5°C from one end of the tunnel to another end. Polycarbonate sheet of 85% light transmission are being used for covering the system. Temperature and Humidity sensors are being mounted at 3 meter interval for data logging option and signals from each sensor are being recorded and monitored and controlled by PLC & SCADA system. Some field temperature gradient tunnels adapted from Rawson *et al.* (1995) are portable and contain the measuring and part of the control equipment. Temperature gradient tunnel facilities can realistically simulate aspects of the effects of projected future environmental change.

Temperature Gradient Tunnel (TGT)

2.2 Open Top Chambers (OTC)

Square type open top chambers (OTC) of 3x3x3 m dimensions, were constructed at the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad (17.38° N; 78.47°E), one for maintaining elevated CO_2 (eCO_2) of 550 ± 25 ppm CO_2 and another one for ambient CO_2 (aCO_2) concentration (380 ± 25 ppm CO_2) and were replicated twice and in total four OTCs were maintained for various experiments to understand the impact of elevated CO_2 on crop plants and insects. Carbon dioxide gas was supplied to the chambers and maintained at set levels using manifold gas regulators, pressure pipelines, solenoid valves, rotameters, sampler, pump, CO_2 analyzer, PC linked Program Logic Control (PLC) and Supervisory Control and Data Acquisition (SCADA). The fully automatic control and monitoring system which includes CO_2 analyzer, PLC and SCADA programme with PC enable to maintain the desired level of CO_2 within the OTC's and along with temperature and relative humidity sensors. The system monitors continuously the concentration of CO_2, temperature and relative humidity within the OTCs. The uniformity of the CO_2 is maintained by pumping CO_2 gas diluted with air by air compressor. The air is sampled from the centre point of the chamber through a coiled copper tube, which can be adjusted to different heights as the crop grows. The equipment is monitored and controlling the CO_2 in OTCs is fully automatic and the desired CO_2 level can be maintained throughout the experimental period in the OTCs (Vanaja *et al.*, 2006, Srinivasa Rao *et al.*, 2012).

Open Top Chambers at CRIDA

2.3 CO_2 Growth Chambers

The CO_2 growth chambers (PERCIVAL I-36LL) are of 800 L. capacity with improved Intellus Ultra Controller (Control system). The interior space of 29.7 ft^3 (0.8 m^3) with work area of 21.6 ft^2 (2.0 m^2) is provided on four tiers. These chambers are mainly used for maintaining the insect culture and conducting the feeding trials using crop foliage obtained from CO_2 enrichment conditions. The chamber has temperature range of 4°-44°C (±0.5°C) lights on and 2°-44°C (±0.5°C) lights off. Additive humidity control of higher than ambient to 80% (±10%) lights on for set temperatures between 15° to 30°C is maintained and also Humidity control of higher than ambient to 90% (±10%) lights off for temperatures between 15° to 30°C. The self-contained air-cooled condensing unit with hot gas bypass system is provided in the chamber for temperature regulation and cooling.

For lighting system fluorescent lamps are horizontally mounted in pairs above each shelf with intensity programmable up to 65 µmoles/m^2/s of light irradiance measured @ 6" from lamps on 2 on/off light events. The CO_2 supply in the range of 0-3000 ppm is provided with appropriate regulatory system attached to CO_2 cylinder.

These facilities have the limitation of not providing simultaneous control of air temperature and CO_2, humidity, which limits the study of combined parameters and thus the concurrent effect of elevated CO_2 and temperature is not possible. These facilities are of small in size and volume and are not akin to field conditions and a small amount of chamber effect is also noticed. Experiments are hampered by an inability to create an experimental environment free of artifacts introduced by the structures and equipment used to expose the target ecosystem to the test conditions (Hendrey & Kimball, 1994). These artifacts are generally described as "chamber effects" and include changes in wind velocity, humidity, temperature, light quality or intensity and soil variables. A more detailed discussion of chamber effects is presented by Allen *et al*. (1993). Both, OTC and FACE facilities systems have restrictions in terms of cost, because CO_2 is emitted freely into the atmosphere. Majority of these limitations will be addressed and rectified in the CTGC facility.

Larval Bioassay


CO_2 Growth Chambers at CRIDA

2.4 Free Air Carbon dioxide Enrichment (FACE)

This facility provide an elevated CO_2 conditions to study the effects of CO_2 enrichment on crop plant growth by maintaining the other environmental conditions without any much change in the micro climate conditions. The simulated CO_2 enrichment conditions are possible with this and various experiments can be conducted to capture the elevated CO_2 impacts. With current FACE technology, CO_2 enriched air is injected around the perimeter of circular plots and natural wind disperses the CO_2 across the experimental area. No walls are constructed among the rings and caution is taken with zero interference with solar radiation and no artificial constraints.

Free Air Carbon dioxide Enrichment (FACE)

2.5 Free Air Temperature Elevation (FATE)

This facility has provision to enhance the artificial canopy temperature in open field conditions without any use of enclosures. This facility is connected with temperature and CO_2 controlling and monitoring system for effective control of temperature and CO_2 concentration. The Control system can measure the data at regular intervals from the weather station (wind speed and direction) along with CO_2 and temperature. This system has nine rings where elevated CO_2, elevated temperature and combination of both (eCO$_2$ + eTemp) were maintained independently in the rings in order to quantify the impacts of elevated temperature on crop growth.

Free Air Temperature Elevation (FATE) at CRIDA

3. Impacts of *e*CO_2 and *e*Temp

3.1. Effect of *e*CO_2

Elevated atmospheric CO_2 (*e*CO_2) concentration influences the crop growth by altering photosynthesis (Norby *et al.*, 1999; Stitt and Krapp 1999; Ainsworth and Long, 2005), stomatal conductivity (Bunce, 2004), shoot root ratio (Rogers *et al.*, 1996; Madhu and Hatfield, 2013), leaf area (Sun *et al.*, 2013), biomass (Prasad, 2005; Gregory *et al.*, 2009), increased carbon (Gutierrez *et al.*, 2008), decreased nitrogen (Dixon *et al.*, 1993) and C:N ratio (Hughes and Bazzaz, 1997; Hunter, 2001; Gutierrez *et al.*, 2008). Changes in plant N concentration, and C: N ratio affects the quality and quantity of food available to insect herbivores (Chen *et al.*, 2007).

3.2. Effect of *e*Temp

Climate change resulting in increased temperature could impact crop pest insect populations in several complex ways. Although some climate change temperature effects might tend to depress insect populations, most researchers seem to agree that warmer temperatures in temperate climates will result in more types and higher populations of insects.

Increased temperatures can potentially affect insect survival, development, geographic range, and population size. Temperature can impact insect physiology and development directly or indirectly through the physiology or existence of hosts. Increased temperatures will accelerate the development of several types of insects (cabbage maggot, onion maggot, European corn borer, Colorado potato beetle). Possibly resulting in more generations (and crop damage) per year. In addition to the above observations some more predictions and generalizations were made by several researchers and are given as follows. For more details please see the articles by Bale *et al.*, (2002); Srinivasa Rao *et al.*, (2009).

Autographa nigrisigna

Phenacoccus solenopsis

Aphis craccivora

Table 1: Impacts of increased temperature on insect pests

Anticipated /Expected effect	Reference
Warmer conditions in temperate regions may lead to the occurrence of new pest species that were previously restricted by unfavourable conditions, and increase the impact of existing pests	Cammell and Knight (1992)
Faster development of insects and may allow for additional generations within a year	Pollard and Yates (1993)
Temperature change gender ratios of thrips by potentially affecting reproduction rates	Lewis (1997)
Increased temperature (IT) influenced the larval development and fecundity of *Operophtera brumata* insects	Dury *et al.*, (1998)
Majority of 'temperate' insect species to extend their ranges to higher latitudes and altitudes. 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 phytochemistry of the host plants and affect the insect growth and development	Williams *et al.*, (2000)
Diversity of insect herbivores and the intensity of herbivory increases with rising temperatures at constant latitude. 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.	Bale *et al.*, (2002)
Sugar concentrations in foliage can increase under drought conditions making it more palatable to herbivores and therefore resulting in increased levels of damage eg. budworm (*Choristoneura fumiferana*) on balsam fir	Mortsch, (2006)
Temperature can also influence the duration of outbreaks as collapses are often associated with the loss of suitable foliage often as a result of late spring frosts	Volney and Fleming (2007)
Insects proliferate more readily in warmer climate than cooler climate. Thus incidence will be more in the areas with IT. (*Myzus persicae*)	Sahai (2008)

Anticipated /Expected effect	Reference
At elevated temperature ectothermic animals, like insects, are more active and probably will grow faster. Some pest species may be able to complete generations in a season rapidly then this may lead to greater pesticide use (Aphids & DBM) Climate change may affect pest control. For example, high temperature is reported to reduce the effectiveness of some pesticides.	Bale *et al.*, (2002) Rosemary Collier (2009)

Insects that spend important parts of their life histories in the soil may be more gradually affected by temperature changes than those that are above ground simply because soil provides an insulating medium that will tend to buffer temperature changes more than the air (Bale *et al.*, 2002). Insect species diversity per area tends to decrease with higher latitude and altitude, meaning that rising temperatures could result in more insect species attacking more hosts in temperate climates. It is to conclude that the diversity of insect species and the intensity of their feeding have increased historically with increasing temperature.

3.3 Interactive effects of *e*CO_2 and *e*Temp

Elevated atmospheric CO_2 levels have negative impacts on the performance of insect herbivores in general, often termed as host mediated or indirect effects. Reduced food quality leads to an increase in crop damage when herbivore insects prefer to have compensatory feeding by consuming more quantity of plant tissues (Coll and Hughes, 2008). Individual insect species responses to *e*CO_2 vary: consumption rates of insect herbivores increase although this does not necessarily compensate fully for reduced leaf nitrogen. Majority of experimental findings under *e*CO_2 suggested that aphids can proliferate in a huge number and become more serious to cause significant damage in crop plants (Cannon, 1998). Aphid responses to *e*CO_2 tested frequently have been "species-specific" and are negative or positive or neutral (Bezemer and Jones, 1998; Hughes and Bazzaz, 2001).

Increase in atmospheric temperature resulted in reduction in survival and increase in developmental rate, resulting in more generations and thus more crop damage per year. Fewer studies show that warmer areas would be favourable for growth in insect populations that insect species would undergo rapid population growth through higher reproduction rates due to higher metabolic rates. Most of the studies indicate insect pests becoming more abundant with elevated temperatures through a number of inter-related processes such as range extensions and phenological changes, as well as increased rates of population development, growth, migration and over-wintering (Forno and Bourne, 1986), but can also facilitate success by shifting the geographic ranges in which plants and insects experience suitable thermal minima and maxima (Lu *et al.*, 2013; Allen *et al.*, 2013).

Increase in temperature and elevated CO_2 (eCO_2) significantly influence the crop growth and in turn affect the insect herbivores both directly and indirectly. Knowledge of the insect response to changes in the environmental variables can provide valuable information for pest management and chemical applications. It is well known that deleterious effects on insect performance (oviposition rate, mortality, growth and developmental time) would be at reduced temperatures. Effects of temperature and CO_2 on insect performance can be direct by changing insects behaviour or indirect by changing the host nutritional quality resulting in changes of feeding behaviour (Stiling and Cornelissen, 2007). Though it is known that the increase in temperature will have a greater effect on insects than the rising CO_2 concentration (Harrington *et al.*, 2001), the interactive and combinational effect of both parameters is more evident. Greater understanding of these dynamics will be essential for understanding plant responses to future climate conditions. Two key variables, eCO_2 and *e*Temp influence plant–insect interactions (Stiling and Cornelissen, 2007; Robinson *et al.*, 2012). The effect of eCO_2 is decrease in host plant quality, particularly through increases in C:N ratio (Bezemer and Jones, 1998; Coviella and Trumble, 1999; Hunter, 2001) and such reductions in plant quality have been shown to increase insect feeding rates to compensate for nutritional deficiencies (Hughes and Bazzaz, 1997).

Further, findings of published information on impact of eCO_2 on insects during one decade (2007 to till date) are presented in the table. Majority studies were conducted on lepidopteran insects on various host plants signifying the impacts on both the host plants and herbivore insects. Succinctly, the information on effects of eCO_2, *e*Temp and combination of both are given below, which shows the significance of eCO_2, *e*Temp either in increasing or decreasing the vital parameters of herbivore insects. In case of collective effects of both either eCO_2 or *e*Temp used to dominate and cause the significant effects. Thus, effect of either eCO_2 or *e*Temp will be discernible. The information on effect of eCO_2 and temperature on crops and herbivore insects was reviewed and presented in the Table 2 most of the studies were conducted on lepidopteran insect pests of forest trees, grasses and few cultivated crops.

Table 2: Effects of *e*CO_2 and *e*Temp and their interactive influence on crops and insects

Insect species		Host plant		Effect on host plants	Impact on insects	Reference
Common Name	Scientific Name	Common Name	Scientific Name			
***e*CO_2**						
Leaf miner	*Acrocercops* sp.	Scrub Oak	*Quercus berberidifolia* Liebm.	Increased biomass, C/N ratio, tannins, phenolics and decreased N.	Increased RCR, DT, total consumption & decreased RGR, conversion efficiency& pupal weight.	Stiling and Cornelissen, 2007
The polyphemus moth	*Antheraea polyphemes* Cramer	White Oak	*Q. alba*, *Q. velutina*	Increased C, C: N, total protein precipitation capacity; decreased N and water content	Increased consumption with slower development, greater mortality	Rachel *et al*. (2007)
Tobacco caterpillar & castor semi looper	*S.litura and Achea janata* (L).	Castor	*Ricinus communis*	Lower N content, higher C, C: N ratio and polyphenols	Increased consumption, larval duration & RCR; decreased ECI, ECD & RGR	Srinivasa Rao *et al*. (2009)
Common sulphur	*Colias philodice* Godart	White colver, alfalfa, lotus	*Trifolium repens*, *Medicago sativa*, *Lotus corniculatus*	Leaf nitrogen remained same or increased, C: N ratio did not change	Increase in RGR, pupal weight unaffected	Karowe and Migliaccio (2011)
The bird cherry oat aphid	*Rhopalosiphum padi* Lin.	Wheat	*Triticum aestivum* L.	Increased above ground biomass	Increased Relative developmental stage (rDS), rm, adult weight (24%) and RGR (18.2%)	Oehme *et al*. (2011)
Tobacco caterpillar,	*S. litura*	Groundnut	*Arachis hypogaea* L.	Lower leaf N, higher C, C:N and polyphenols content - tannic acid equivalents (TAE)	Increased larval duration, larval weight, consumption & RCR; decreased ECI, ECD, RGR	Srinivasa Rao *et al*. (2012[a])
Bihar hairy caterpillar	*Spilosoma oblique* Walker	Castor	*Ricinus communis*	Lower leaf N, higher C, C:N and higher polyphenols - tannic acid equivalents (TAE)	Increased consumption, larval weights, larval duration, AD & RCR; reduced ECI, ECD &RGR	Srinivasa Rao *et al*. (2012[b])

Insect species		Host plant		Effect on host plants	Impact on insects	Reference
Common Name	Scientific Name	Common Name	Scientific Name			
Russian wheat aphid	*Diuraphis noxia* Kurdjumov	Barley	*Hordeum vulgare* L.	Increase in the leaf C:N.	Increased populations	Jimoh *et al.* (2013)
Four Spotted Cup Moth	*Doratifera quadriguttata*	Eucalyptus	*Eucalyptus tereticornis* Sm.	Reduced foliar quality	Reduced DT	Murray *et al.* (2013)
American bollworm	*H. armigera*	Chickpea	*Cicer arietinum* L.	Lower N, higher C and C:N ratio	Increased FC, extended LD & lower fecundity	Abdul khadar *et al.* (2014)
American bollworm	*H. armigera*	Chickpea	*Cicer arietinum* L.	Increased defensive enzymes	Decreased larval survival	Sharma *et al.* (2016)
Tobacco caterpillar	*S. litura*	Soybean	*Glycin max* (L.) Merr.	-	Prolonged duration of larva, pupa, adult & decreased pupation, fecundity, RGR	Zhang *et al.* (2017)
Tobacco caterpillar	*S. litura*	Groundnut	*Arachis hypogaea* L.	Lower leaf N, higher C, C:N, phenols and tannins	Reduced fecundity, ECI, ECD and RGR. Increased AD and RCR.	Shwetha *et al.* (2017)
Aphid	*A. craccivora*	Groundnut	*Arachis hypogaea* L.	-	Reduced DT and increased thermal requirement	Srinivasa Rao *et al.* (2017)

Insect species		Host plant		Effect on host plants	Impact on insects	Reference
Common Name	Scientific Name	Common Name	Scientific Name			
***e*Temp**						
Nun moth, and the Gypsy moth	*Lymantria monacha* (L.); *Lymantria dispar* (L.)	Scots pine; Common oak	*Pinus sylvestris; Quercus robur*	-	Reduced growth period	Karolewski *et al.* (2007)

Insect species		Host plant		Effect on host plants	Impact on insects	Reference
Common Name	Scientific Name	Common Name	Scientific Name			
Cotton Aphid	*Aphis gossypii* Glover	Cotton	*Gossypium hirsutum* L.	-	Increased RR	Nimbalkar *et al.* (2010)
Cotton aphid	*Aphis gossypii* Glover	Cotton	*Gossypium arborium* L.	-	Reduced RR & increased mortality	Guizhen *et al.* (2012)
Yellow Stem Borer	*Scirpophaga incertulas* Walker	Rice	*Oryza sativa* L.	-	Reduced development time	Manikandan *et al.* (2013)
Tobacco caterpillar	*S. litura*	Soybean	*Glycin max* (L.) Merr.	-	Reduced larval and pupal duration & Increased RGR	Zhang *et al.* (2017)

Insect species		Host plant		Effect on host plants	Impact on insects	Reference
Common Name	Scientific Name	Common Name	Scientific Name			
***e*CO_2 + *e*Temp**						
Leaf miner	*Dialectica scalariella Zeller*	Paterson's curse	*Echium plantagineum* L	Increased C, C:N, biomass, leaf thickness & reduced N	Reduction in DT & survivorship	Johns and Hughes, (2002)
Polyphagous weevils	*Phyllobius maculicornis* Germ.	Silver birch	*Betula pendula* Roth.	Decreased N, flavonol glycosides & increased phenolics, tannins, catechin	No differential response in feeding to *e*Temp and the combination of *e*CO_2+*e*Temp.	Kari *et al.* (2003)
Madeira mealybug,	*Phenacoccus madeirensis* Green	Chrysanthemum	*Dendranthema grandiflora*	No change in chemical composition	Increased egg survival; shortened duration of egg eclosion &DT of adults.	Chong *et al.* (2004)

Insect species		Host plant		Effect on host plants	Impact on insects	Reference
Common Name	Scientific Name	Common Name	Scientific Name			
Aphids	*Myzus persicae* (Sulzer)	Rapeseed	*Brassica napus ssp.napus*	Elevated temperature decreased C and N contents, total chlorophyll and carotenoids	Reduced DT & adult weight	Himanen *et al.* (2008)
Yellow sugarcane aphid	*Sipha flava* (Forbes)	*In vitro*	-	-	Reduced nymphal duration, longevity and RR	Auad *et al*. (2012)
Japanese beetle	*Popillia japonica* Newman	Soybean	*Glycin max* (L.) Merr.	No differences in leaf chemistry	No interactive effects of CO_2 and temperature	Niziolek *et al.* (2013).
Lucerne weevil	*Sitona discoideus* Gyllenhal	Alfalfa	*Medicago sativa*	Increased plant growth & root nodulation increased and decreased, respectively.	Larval emergence was increased initially but later diminished.	Ryalls *et al.* (2013)
BPH	*Nilaparvatha lugens* (Stal.)	Rice	*Oryza sativa* L.	Increased stem height, biomass & reduced water content	Higher fecundity	Kun *et al*. (2014)
American bollworm	*H. armigera*	Cotton	*Gossypium hirsutum* L.	-	Increased food consumption and metabolism of larvae by enhanced enzyme activity	Akbar *et al.* (2016)
Tobacco caterpillar	*S. litura*	Soybean	*Glycin max* (L.) Merr.	-	Decreased RGR	Zhang *et al.* (2017)

Table 3: Trends in impacts of eCO_2, *e*Temp with host & insect herbivore interactions

Effect		Reference
***e*CO₂**		
Mortality of Larvae	↑	Rachel *et al.* 2007; Sharma *et al.* 2016; Srinivasa Rao *et al.* 2016
RCR & ECI, AD of Lepidopteran Larvae	↑	Stiling and Cornelissen, 2007; Srinivasa Rao *et al.*, (2014 & 2016); Swetha *et al.* 2017.
Leaf consumption	↑	Stiling and Cornelissen, 2007; Rachel *et al.* 2007; Srinivasa Rao *et al.* 2009, 2012, 2014 & 2017; Abdul khadar, 2014.
Larval, pupal and adult duration	↑	Srinivasa Rao *et al.* 2012, 2014 & 2017; Abdul khadar, 2014; Zhang *et al.* 2017;
r_m of aphids	↑	Oehme *et al.* 2011; Srinivasa Rao *et al.* 2016 & 2017
DT of aphids	↓	Murray *et al.* 2013
RGR &Fecundity of Lepidopterans	↓	Stiling and Cornelissen, 2007; Abdul Khadar, 2014; Swetha *et al.* 2017; Zhang *et al.* 2017
ECI, ECD	↓	Srinivasa Rao *et al.* 2012; Swetha *et al.* 2017
***e*Temp**		
RGR of Lepidopterans	↑	Zhang *et al.* 2017
Fecundity in aphids	↑	Xie *et al.* 2014; Aleosfoor & Fekat, 2014
Potential for insect outbreaks	↑	Bale *et al.* 2002
Insect extinctions	↑	Thomas, 2004
Northward migration	↑	Parmesan, 2006
RR of aphids	↓	Guizhen *et al.* 2012
Larval & pupal duration	↓	Zhang *et al.* 2017
DT of aphids	↓	Mohammad, 2010; Aleosfoor & Fekat, 2014
Parasitism	↓	Hance *et al*, 2007
***e*CO₂+*e*Temp**		
Egg survival	↑	Chong *et al.* 2004
Fecundity in BPH	↑	Kun *et al.* 2014
Metabolism and enzyme activity	↑	Akbar *et al.* 2016
DT of leaf miner, mealybugs and aphids	↓	Johns and Hughes, 2002; Chong *et al.* 2004; Himanen *et al.* 2008
Survivorship	↓	Johns and Hughes, 2002;
Nymphal duration, longevity, RR	↓	Auad *et al.* 2012
RGR	↓	Zhang *et al.* 2017
No differential response	--	Kari *et al.* 2003; Niziolek *et al.* 2013.

4. What is CTGC?

CTGC is a Carbon dioxide and Temperature Gradient Chamber, realistically designed facility for measuring the impacts of elevated CO_2 and temperature which are vital parameters of climate change. The chamber is with field like environment with higher CO_2 and warming conditions concurrently which influence the crop growth and insect pests. Very meagre data is available to assess the potential interactive impacts of elevated CO_2 and temperature under field like conditions. This facility is first of its kind to simulate the future climate change scenario conditions with both CO_2 enrichment and warming conditions. The scientific parameters generated from the experiments conducted using this facility are of with authenticity and of immense help to understand the impact of climate change on crop growth and biotic stresses.

Earlier, the structural design on temperature gradient chamber by Mihara (1971) was refined and attempted to construct a new temperature gradient chamber (CTGC) (Lee *et al.*, 2001) compounded with CO_2 gradient allowing a wider use. At CRIDA, CTGC was constructed with new concept, scientific philosophy and by adopting the new design and integration of the components.

4.1 Structure of CTGC

The CTGC facility has 8 chambers with 30 meters length, 6 meters width and 4 meters height at the centre. The 8 chambers are categorized as follows:

1. Two chambers are with natural climate which serve as - 'Reference'.
2. Two Chambers are with temperature gradient of 5 ± 0.5°C over reference and referred as elevated Temperature, - '*e*Temp'.
3. Two Chambers are with Temperature gradient 5 ± 0.5°C over reference with elevated CO_2 concentration of 550 ± 50 ppm – '*e*Temp + *e*CO_2'
4. Two Chambers are with elevated CO_2 concentration of 550 ± 50 ppm which serve as - '*e*CO_2'

Structure of CTGC

Eight CO_2 temperature gradient chambers at HRF, CRIDA

The detailed information on CTGC is explained hereunder:

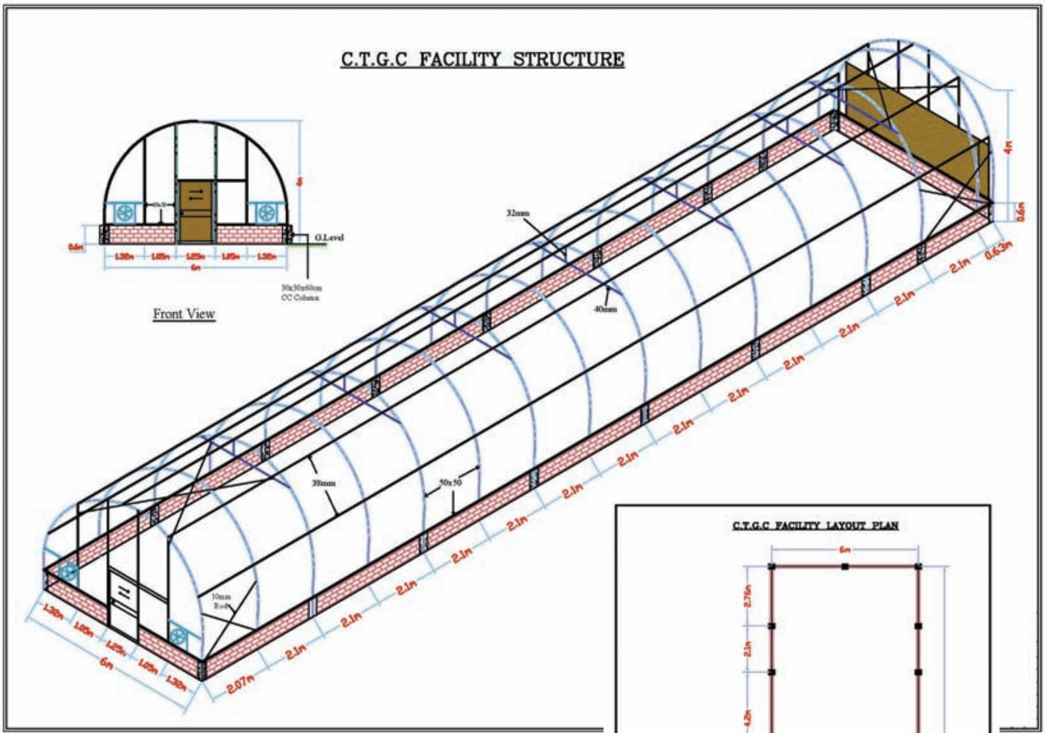
4.2 Major components of CTGC

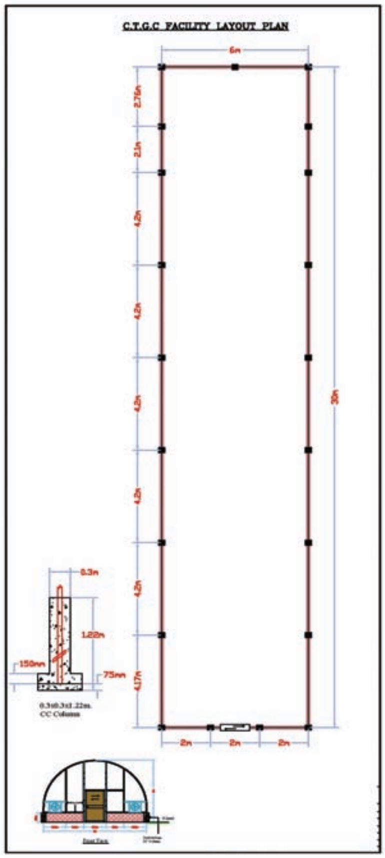
i. Chamber design

Each chamber is 30 meters of length, 6 meters width and 4 meters height at the centre. The chambers are provided with sufficient strength to maintain 30x6x4 meter chamber size. These are covered with high quality, light weight, rigid, multi layered (corrugated) polycarbonate sheet of Lexan quality with excellent impact resistance, superior clarity, versatility and weather resistance. The thickness of the sheet is 6mm and has >90% light diffusion with > 85% PAR (Photosynthetically Active Radiation) transmission.

Front View

Inner View


C.T.G.C FACILITY STRUCTURE
Front View
G.Level
32mm
40mm
38mm
50x50
4m
0.6m
0.63m
2.1m
2.07m
6m


C.T.G.C FACILITY LAYOUT PLAN
6m
30m
2m
0.3m
1.22m
150mm
75mm

ii. Heating system

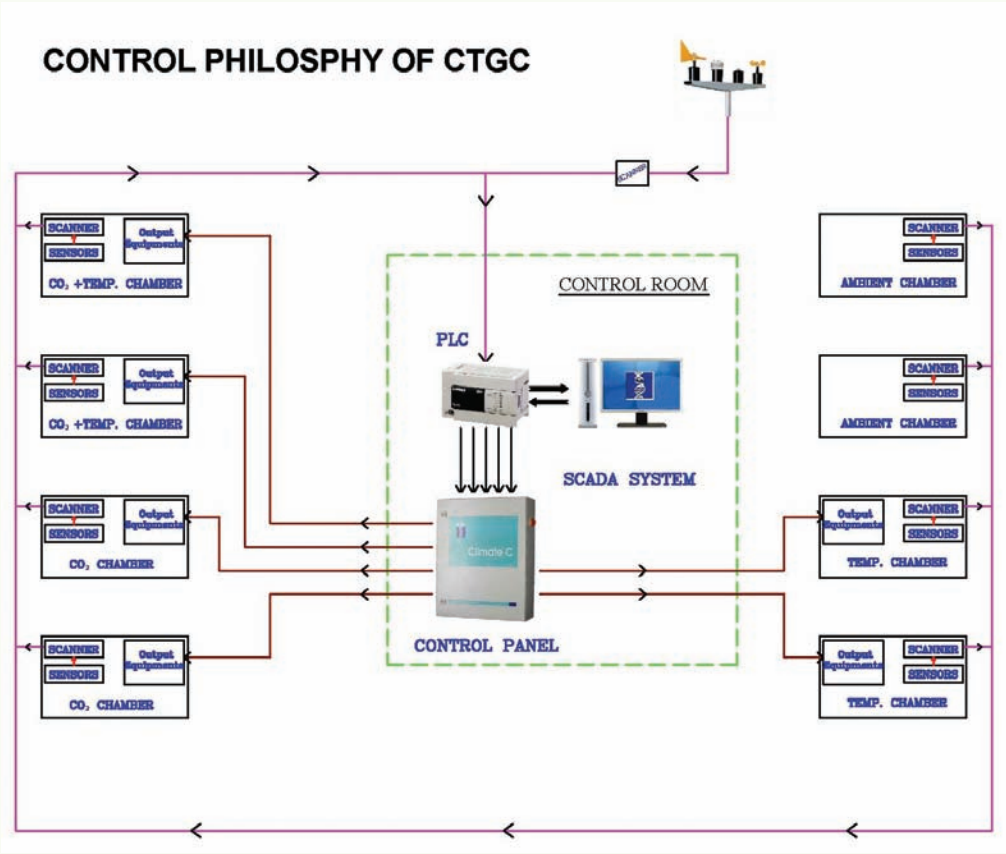
The heating system in four CTGC chambers consisting of 2 for temperature and 2 for both temperature and CO_2 is provided with infrared heaters. The gradient of 5 ± 0.5°C above ambient increase in temperature within each chamber with 1 ± 0.5°C increase at regular interval is set with proper control and regulation. The heating system employed is in a self-contained sheet steel enclosure. Each chamber fitted with six such heating and circulating units. Each device has heat generating capacity 2400 watts aggregating to 15000 watts in each chamber. This maintains the desired temperature range over and above the ambient temperature. All the heating devices are controlled through PLC as per SCADA programe for temperature management with independent chamber control.

Heating system

The temperature settings have a cut off for above 50 ± 0.5°C under any circumstances. The provision to program variable temperatures for different durations is also provided. Further, an in-built alarm system for different trouble shooting events is provided.

iii. CO_2 supply system

CO_2 supply system is consisting of CO_2 tank of 20 Kilo litres Liquid CO_2 capacity with all necessary accessories to maintain the liquid, gas pressure and with relevant safety devices. This tank was installed on a RCC basement in accordance to Indian standards. The license was obtained from Mandatory state agencies for CO_2 tank. SS 304 grade seamless Tubing was done for CO_2 supply from the CO_2 tank site to the CTGC chambers. Enough caution was taken to have pressure compatibility from Tank side to free release bearing capacity of each chamber. Due care was also taken for elimination of leakages if any in the entire SS 304 grade tubing. The installation of CO_2 tank was done in line with the norms of licensing authority (PESO). The chambers with elevated CO_2 are provided with proper monitoring system and controls to maintain uniform CO_2 concentration vertically and horizontally even in combination with gradient temperature condition.



20 Kilo litres CO_2 tank

Supply of CO_2 gas through Pipelines from CO_2 tank to respective CTGC chambers with regulators and pressure gauges

iv. Control panel

Control panel consisting of temperature, humidity and CO_2 controller with software PC linked Program Logic Control (PLC) and Supervisory Control and Data Acquisition (SCADA) control systems. Control Panel consisting of Temperature dynamic +5°C ± 0.5°C, Humidity & CO_2 controllers with Mitsubishi FX3u-32 M PLC, Digital Expansion Block Mitsubishi FX2n-16EYT, RS-485 Interface Module Mitsubishi FX3u-485ADP & xarrow SCADA control system. The complete control system is housed in Electric console.

v. Air circulating unit

Air circulating unit has cooling pads, water pumping and supply from water stored tanks of 1000 litres capacity. The water is pumped and distributed continuously over cooling pads installed at the one end of the chamber. This unit is provided for maintaining the set humidity and temperature with at least 90% efficiency to attain a maximum of 80% RH. The humidity was maintained by adopting good number of foggers on both sides of the chamber and are automatically connected to sensors so that foggers would switch on & off at regular intervals.

HEPA filter that captures all particles 0.3 micron or bigger are incorporated for achieving aerosol disinfection. Two exhaust fans at the front end of the chamber are there to standardize the air temperature and CO_2 concentration in the chamber as per the set readings.

Outer View

Inner View

Foggers for maintenance of set RH

Fans for air circulation

vi. Temperature sensors and control

The RH + Temperature transmitter installed is of Redix make model number SC807. This is a micro-controller based, high performance 2-wire RH+T transmitter. It can be factory configured for 2 x RH outputs, 2 x Temperature outputs, or 1 x RH + 1 x T output. However the configuration employed here is for 1 x RH + 1 x T output. It has 2 x 4-20 mA outputs with True 2-wire operation for accuracy of ± 2% RH, ± 0.5°C, it's a PC programmable using PC configurator PCC82. The sensor technique employed is Capacitive for RH, Semiconductor (Band gap) for temperature. The ambient temperature is sensed with weather station made by Virtual Electronics for temperature range -40 to 123.8°C with accuracy ± 0.5°C. Analog Input Module employed is made by Radix Electro Systems Pvt Ltd with 8 channels, each with universal analog inputs capable of connecting 8 thermocouples, Linear input - 0~50 mV, 0/4~20 mA, communication ports isolated RS485/ MODBUS RTU, up to 19200 Baud with user programmable. Its scalable with 3 key tactile keypad, non-volatile, indefinite duration 3 key programming.

Temperature and RH sensors

vii. CO_2 analyzer and sensors

CO_2 monitoring is done by micro processor based CO_2 analyzer with non-dispersive infrared absorption (NDIR) measuring method. The repeatability of the CO_2 analyzer is found to be within ± 0.5% of full scale and response time of 1-3 seconds; Within ± 1% of linearity; ± 0.5% of noise of full scale; With in-built temperature and relative humidity measurement facility. Before air sample enters the analyzer, it was passed from the moisture removal device to safe guard the analyzer from excess humidity. The provision for measuring CO_2 concentration is made through 6 sampling points in each chamber and are interfaced with SCADA and PLC.

CO_2 analyzer with sensors

viii. Data management system

Data management system is done for SCADA and PLC by using the Computer system along with needful accessories. The data on various parameters *viz.*, temperature, relative humidity, CO_2 concentration recorded at each gradient of the chamber is recorded at 5 minutes interval and same is obtained in the computer.

ix. Standard signal cables

Standard signal cable is provided for connecting sensors to the PLC/SCADA system in control room. Cables are of standard make and ISI certified and enough caution was taken to avoid any signal loss in the wires while connecting from source to the SCADA. Cables system has ferrules and identifiers for easy identification in the field to facilitate easy maintenance.

4.3. Functionality of CTGC

In CTGC facility the air in the chambers is heated by the natural solar radiation and by using heaters. The temperature well within chambers is elevated by adopting heaters of capacity. The temperature gradient is achieved by maintaining the air inlet and outlet and cooling/heating mechanism. The cooling pads are arranged at one end of the chamber and the other end exhaust fans are maintained to facilitate air inlet and outlet system. The water is circulated along with cooling pads and thus temperature gradient is maintained. The cooling/heating rate is controlled by Programming Logical Controller (PLC) based on temperatures measured inside the chamber.

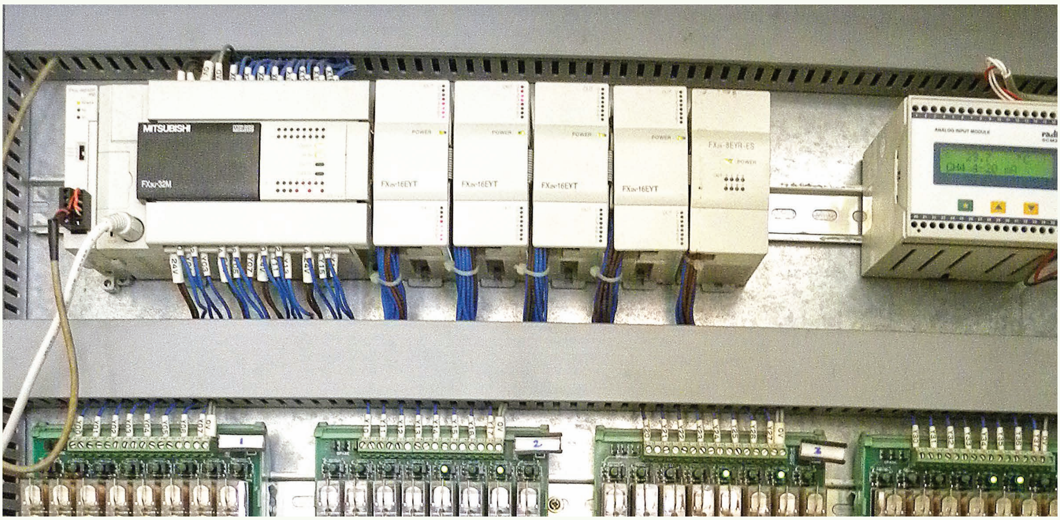
Cooling pads for water circulation with water supply tank

4.4. Integration of Components

The CTGC facility has eight chambers in which the entire control system monitors the temperature, RH and CO_2 of each chamber and outside temperature also. The control system contains broadly four major components and the details are given hereunder

i. PLC

This Mitsubishi FX3U series PLC incorporates power supply, CPU, and I/Os into a single compact unit. Meets the needs of user applications with options for I/O, analog, positioning, and open network expansion with high speed, high functionality, and expandability. Depending on control points, total 384 I/O extension devices can be connected. Function can be easily added by mounting a function expansion board to the main unit. Its I/O is connected in connector format, reducing wiring effort. FX3U can count at high speed input frequency 100 kHz (1-phase 6 pts), 50 kHz (2-phase 2 pts), 10 kHz (1-phase 2 pts).



Program Logic Control

ii. SCADA (Supervisory Control and Data Acquisition) control system

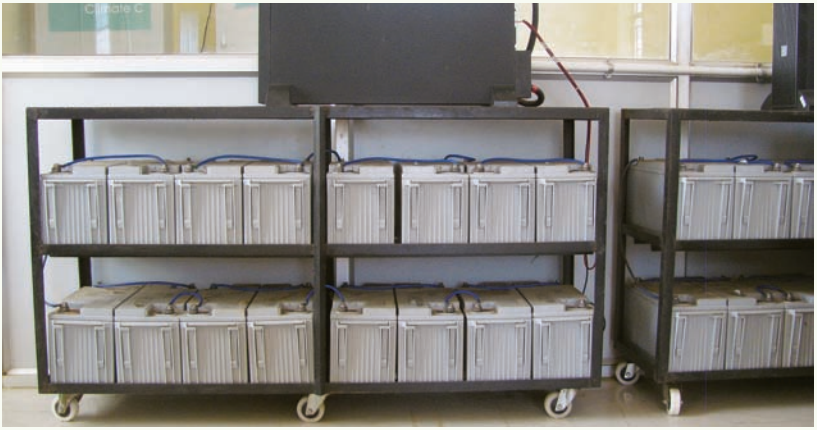
A supervisory computer is the core of the SCADA system which is gathering data of all eight chambers on the process/status and sending control commands to the field connected process/status devices. A high performance Graphical HMI is the front end of operator with Xarrow trade name. Data acquisition begins at the PLC level and includes instrumentation readings and equipment status reports that are communicated to SCADA as required. Data is then compiled and formatted in such a way that a control room operator using the HMI

(Human Machine Interface) can make supervisory decisions to adjust or override normal PLC controls. Data is also fed to a historian, built on a database management system, to allow trending and other analytical auditing. The present supervisory computer is connected via a USB to serial link to the PLC.

The SCADA program has a user configured database which provides the software about the connected instrumentation and parameters which are to be accessed. The database also have information on how often the parameters of the instruments are accessed and if a parameter is a read only value (e.g. a measured value) or read / write, allowing the operator to change a value (set point).

The SCADA software continuously updates its own database with the latest analogue while functioning. The digital values collected from the PLC and allow real time calculations to be made on the received data and the results would be available as a “virtual” value.

SCADA software showing the layout of CTGC chambers



UPS backup for data management system and control panel

iii. 8-Channel analog input module - Scanner

The Analog Input Module or Remote I/O For PLCs employed in this facility is Redix SCM201, which is a System Integrator for PLCs and SCADA. This module has 8 input channels. Each channel has a universal input - 8 thermocouples, RTD Pt100, 0/4~20 mA and 0~50 mV can be user programmable. The Analog Input Module has an isolated RS485 / MODBUD RTU port for communication. Rates can be 4800, 9600, 19200, 38400 and 57600 baud. Data formats such as integer x 10, integer, float and swap float are user selectable. Has inbuilt SMPS for 85 to 265 VAC, 50/60 hz field supply conditions. Other important parameters such as 4-20 mA output option, selectable resolution, display bias and channel skip makes this the basic analog input module for multiplexing. Its 2x16 backlit LCD allows all important data to be viewed at field with 3 key, 3 level programming.

A Scanner is a device that measures more than one reading points or multi-channel. It is actually a multi-channel indicator that measures and displays signals of each channel one-by-one up to last channel and then returns to first channel and continues the process cyclically. This continuous cyclic process of measurement is called scanning. In CTGC temperature, humidity and CO_2 is measured by using a scanner.

iv. Switching unit panel

All the 8 chambers have switching unit panels independently. This switching panel has a plastic IP65 enclosure deigned to work in high temperature and high humidity conditions. Switching unit panel gets signal from PLC and accordingly it runs the output equipments like: Ventilation Fan, Heaters, CO_2 solenoid valves and circulation fan etc. Switching panels has suitable electrical contractors and safety devices.

4.5 Concept of CTGC

i. Structural

The facility has eight chambers with 30m length and 6m width and 4m height at centre and eight chambers are categorized independently as explained earlier. The air in the chamber is heated by the solar radiation and heaters and the temperature gradient is achieved by flowing the air from inlet to the outlet. The cooling and heating is controlled based on fluctuation of air temperatures caused by the changes in solar radiation. The cooling and heating is controlled by PLC based on temperature measured inside the chamber. The CO_2 is supplied through PU tubing along the inner wall of CTGC. The CO_2 supply is totally controlled by PLC through solenoid wall. All data on temperature and CO_2 concentration in the chamber is monitored individually by the dedicated computer using SCADA.

ii. Sensing

Temperature: Each chamber of CTGC is equipped with sufficient number of sensors with higher precision and accuracy. Each chamber is provided with 12 temperature and relative humidity sensors controlled by the PLC to maintain temperature gradient of 5.0 ± 0.5°C over reference chamber (Ambient). The temperature sensors have measuring capacity of 0-100°C with an accuracy of 0.5°C and a resolution 0.02%. Similarly RH has range of 0-100% with accuracy of 2% and a resolution of 0.02%.

Carbon dioxide: In CO_2 controlled chambers CO_2 is monitored by the micro processor based CO_2 analyzer with Non-Dispersive Infrared (NDIR) absorption measuring method. The precision of CO_2 analyzer is within ±0.5% of full scale and response time of 1-3 seconds; with ±1% of linearity; ±0.5% of noise of full scale. The provision of measuring CO_2 concentration is through 6 automatic sampling points in each chamber by a dedicated CO_2 analyzer and interfaced with SCADA and PLC. For CO_2 control a separate sensor is provided with ±30 ppm accuracy and 0-2000 ppm scale.

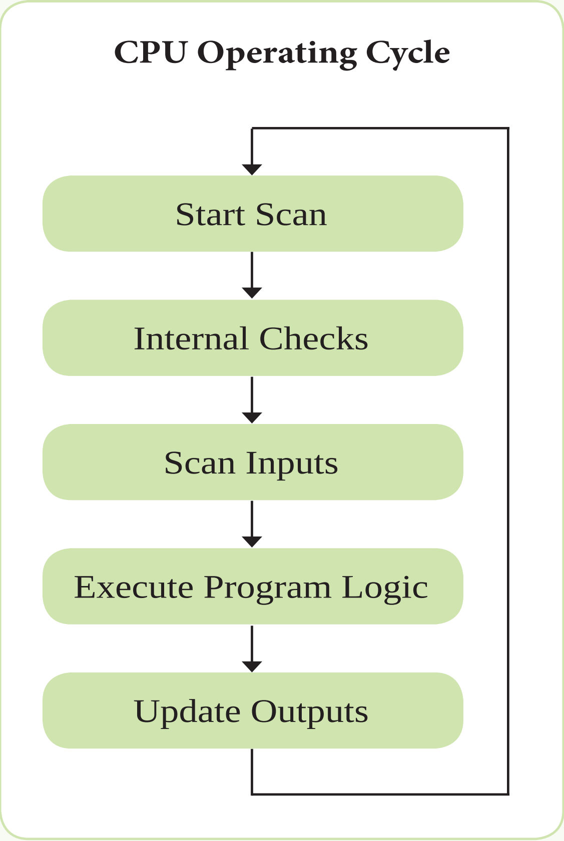
iii. Maintenance of temperature gradient

The temperature within the chamber is maintained with a gradient up to 5°C ± 0.5°C by adopting cooling pads and 36” cooling Fan at both the ends of the chamber. The water is circulated continuously into the cooling pads by giving the provision of water supply in 1000 lit capacities of tanks which were arranged below the ground near chambers. The water is pumped gently into the cooling pads. Enough caution is taken to see that pads are wet continuously without any gap. After consideration of total CFM (cubic feet per minute) of the chamber (30m x 6m x 3.8m = 24500 CFM), two fans of 36” size are arranged to meet the requirement of total CFM as CFM of each 36” fan is 13105 CFM. Thus two fans are able to meet the total CFM which is required to maintain the required temperature gradient up to 5^{o}C ± 0.5^{o}C from Pad to Fan.

iv. Control through PLC system

A PLC system is used to control the desired CO_2 and temperature conditions of the CTGC chambers. PLC system scans the inputs with the help of scanners and gets the output and immediately updates the output which can offer signal to the particular equipment to initiate its operation.

The CPU of PLC works as follows:



v. Monitoring

Monitoring of the data will be done with the help of computer which serves as a human machine interface with high end SCADA software. The real time data of eight chambers is visible in SCADA and we can monitor the data continuously. The status of Heaters, Solenoid Valve, Cooling Fan and other connecting output equipments can be known with the help of SCADA. It also provides historical trend and data grid so that we can access all past data over graph or excel sheet.

4.6. Data control / Processing unit

Data management system for SCADA and PLC includes computer system with Monitor 21.5" LED, TFT with red eye protection; windows 7 professional with licensed key and original CD, Intel CoreTM i7 processor with suitable chipset and high processor speed (15M Cache, up to 3.90GHz), 64GB DDR3 ram, 64 bit, 4 DIMM sockets for memory slots, 4 nos bays (2 nos 5.25" for optical media drives and 2 nos. 3.5" for hard disk drives), 500 GB SATA hard disk drive (7200 rpm), Super multi SATA DVD writer, MS office 2007, 6 USB ports, head phones and microphone ports in front, standard key board with all provisions, the others include, optical two button scroller mouse, network interface integrated 10/100/1000 base T network interface, antivirus: kaspersky with original CD, Multimedia graphic card. Data storage and accessible unit and cables were included.

Data management system with control panel connectivity

5. Experimentation

The land within the chambers was ploughed thoroughly using cultivator mounted on mini tractor. The land was cultivated three times both longitudinally and horizontally to obtain good tilth condition.

Preparatory cultivation within the chamber using mini tractor

Maintenance of different crops in the chamber

Groundnut crop cultivars (Dharani and K6) were sown in chambers which represent i. reference, eCO_2, eTemp and eCO_2+ eTemp conditions. The chambers of eCO_2 and combination (eCO_2+ eTemp) were programmed at eCO_2 (550 ± 25 ppm).

Crops were sown by taking the 45x20 cm spacing and optimum population was maintained. The recommended package of practices of tract was followed. Plant density was maintained properly to avoid congestion in the area. The crop was maintained at insecticide free condition to understand the impact of CO_2 and temperature on insect pests.

Early and late stage of crops in CTGC

5.1. Objectives

The broad objectives envisaged in the programme using CTGC chamber are given below:

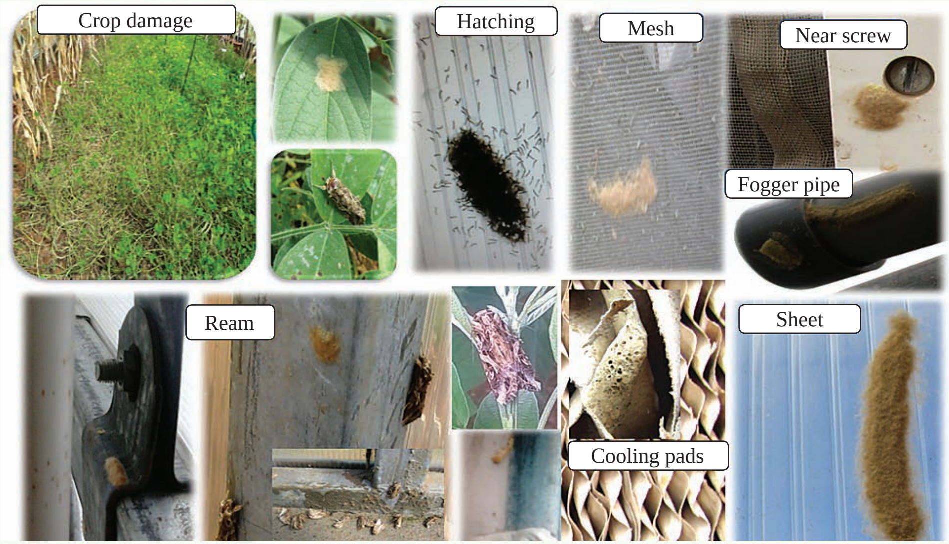
- Population dynamics of various insect pests with a response to *e*CO_2 and *e*Temp conditions.
- Interactive effect of *e*CO_2 and *e*Temp on growth and development of *Spodoptera litura* on groundnut and sunflower, *H. armigera* on maize and chickpea etc.
- Studies on dissipation and persistent toxicity of various insecticides at *e*CO_2 and *e*Temp conditions.
- Quantification of tritrophic interactions (host – insect herbivore – natural enemy)

i. Population dynamics of various insect pests with a response to *e*CO_2 and *e*Temp conditions on groundnut crop

In each chamber at set condition of *e*CO_2 and *e*Temp absolute population of insect per plant were recorded as per the standard procedures. In case of groundnut, the incidence of tobacco caterpillar, *S. litura*, aphids, *A. craccivora*, were recorded.

The observations were noted at weekly intervals coinciding with the Standard Meteorological Weeks (SWK). The corresponding data on temperature at different gradient levels, RH were recorded along with micro climate variables (Canopy Temperature, Air Temperature, Canopy Air Temperature Deficit (CATD), RH well within Crop Canopy (CRH), Surface Soil Temperature (SST).

Crop stand in eCO_2 & eTemp chamber



Severity of S.litura at eCO_2 + eTemp chamber

Severe incidence of *S. litura* was noticed in the *e*CO_2 + *e*Temp conditions across six temperature gradients and higher was noticed at warm (35 ± 1^0C) temperature conditions. Adult female moths laid eggs not only on canopy but also on various parts of the chamber including cooling pad, polycarbonate sheet, pipeline, mesh, ream, fogger pipe, screw etc. as shown above.

Incidence of aphids and mealy bug with coccinellids

Incidence of mealy bug, *Phenacoccus solenopsis* and aphid, *A. craccivora* was noticed in severe form under eCO_2 + *e*Temp conditions over ambient. Higher occurrence of coccinellid predators was also noticed.

Larval and adult stages of *Spodoptera litura*

Harvesting of the crops

Maintenance of CTGC

Monthly once the polycarbonate sheets were cleaned outside to remove the dust, soil and other any inert material deposits by using water. This facilitated the improvement of light transmission and avoidance of reduction of PAR.

6. Conclusions

Impacts of eCO_2 and temperatures are studied individually using various facilities like Open Top Chambers, Temperature gradient tunnels and growth chambers. CTGC facility is very unique and first of its kind to study the interactive effects of eCO_2 and Temperature on crops and insects pests. By using this facility the simulation of future climate change scenario is possible with elevation of both CO_2 and temperatures which are the major two dimensions of climate change. This facility consists of eight chambers with sufficient area to raise different crops within the chambers. The light transmission and PAR are higher than 85 per cent in the chamber and equally comparable with outside open conditions. Crops are grown without any etiolation *i.e.*, long, weak stems; smaller leaves due to longer internodes; and a pale yellow color (chlorosis). The data generated by using this facility will be of authentic in nature and convey the complete effect of CO_2 and temperature.

Inauguration of CTGC facility by Dr. Trilochan Mohapatra, Secretary, DARE and Director General, ICAR at Hayathnagar Research Farm, ICAR-CRIDA.

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Abbreviations

aCO_2 - Ambient Carbon dioxide
AD - Approximate Digestibility
C - Carbon
C:N - Carbon Nitrogen Ratio
CATD - Canopy Air Temperature Deficit
CFM - Cubic Feet per minute
CTGC - CO_2 and Temperature Gradient Chamber
DR - Developmental Rate
DT - Developmental Time
ECD - Efficiency of Conversion of Digested food
ECI - Efficiency of Conversion of Ingested food
eCO_2 - Elevated Carbon dioxide
*e*Temp - Elevated temperature
FACE - Free Air Carbon dioxide Enrichment
FATE - Free Air Temperature Elevation
FC - Food Consumption
GMST - Global Mean Surface Temperature
HRF - Hayathnagar Research Farm
ICAR - Indian Council of Agricultural Research
IPCC - Intergovernmental Panel on Climate Change
N - Nitrogen
NDRI - Non Dispersive Infrared Absorption
OTC - Open Top Chambers
PAR - Photosynthetically Active Radiation
PLC - Programme Logic Control
RCR - Relative Consumption Rate
RGR - Relative Growth Rate
RH - Relative Humidity
r_m - Intrinsic rate of increase
RR - Reproductive Rate
SCADA - Supervisory Control and Data Acquisition
SST - Surface Soil Temperature
TAE - Tannic Acid Equivalents
TGT - Temperature Gradient Tunnel

Four set conditions of CTGC

Reference Chamber

eTemp

eCO_2 + *eTemp*

eCO_2

Visitors to CTGC







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