Effects of Climate Change on Insect Pests of Forests, Grasses and Crops

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Human activities have increased the atmospheric concentrations of greenhouse gases and aerosols since the pre-industrial era. The atmospheric concentration of greenhouse gases reached their highest recorded levels in the 1990s, primarily due to the combustion of fossil fuels, agriculture and land use changes. Global atmospheric CO_2 concentration has increased by approximately 30% since the industrial revolution and is believed to be responsible for an increase of ~0.6°C in mean annual global surface temperature. If no climate policy interventions are made, the concentrations of atmospheric CO_2 may increase upto 405-460 ppm, 445-640 ppm and 540-970 ppm by 2025, 2050 and 2100 respectively. Similarly global mean temperature may increase by 0.4-1.1°C, 0.8-2.6°C and 1.4-5.8°C by corresponding periods respectively. It is very likely that 20th century warming contributed significantly to the observed rise in global average sea level and increase in ocean-heat content. Snow covers and ice extent decreased. Precipitation was very likely increased by 5 to 10% over most mid and high latitudes of the northern hemisphere continents. Changes in stream flow, floods and droughts were observed (IPCC, 2001). Apart from the effects mentioned above, agriculture including plants-insect-parasitoid systems is likely to be affected by the climate change.

Effect of elevated CO_2

a) Phytochemistry of plants

Among the host plants, forest trees and grasses have been extensively studied for insect-plant interactions under elevated CO_2 (Table1).. Few studies are available on cultivated crops. In majority of studies the elevated CO_2 mentioned ranged from 530 ppm to 1050 ppm.

Nitrogen concentration decreased in European white birch, *Betula pendula*, quaking aspen *Populus tremuloides*, condensed tannin increased levels in european white birch trees, quaking aspen, tremulacin levels increased in birch trees. Starch concentration increased in paper birch and pine trees, *Pinus taeda*.

As in case of forest trees nitrogen decreased in many of the grasses except annual blue grass in which there was no effect on nitrogen concentration. In erect brome, *Brumus erectus*, vernal sedge, *Carex caryophylla* and Fescue, *Festuca* sps; increased CO_2 concentration resulted in increase in nonstructural carbohydrates and condensed tannins. C:N ratio increased in red fesue, *Festuca rubra*.

As in case of forest trees and grasses a decrease in nitrogen was observed in cultivated plants like cotton, *Gossypium hirsutum*, mungbean, *Vigna radiata*, spring wheat, *Triticum aestivum* and birdsfoot trefoil, *Lotus corniculatus* . C:N ratio increased in cotton and birdsfoot trefoil . Starch concentration increased in mungbean, wheat and common beet, *Beta vulgaris*. There was an increase in sugars in mungbean, wheat and birdsfoot trefoil.

b) Effect on insects

I) Through host-plant

The impact of elevated carbon dioxide on host plants and insects is comprehensively reviewed and presented in Table 1. Among the orders of class insecta, Lepidoptera was mainly studied with gypsy moth *Lymantria dispar* and forest tent caterpillar, *Malacosoma distrria* were studied exclusively.

i) Lepidoptera

Elevated CO_2 had negative effect on performance of gypsy moth, which was studied extensively on an array of trees. Relative growth rate declined by 30% on sessile oak, *Quercus petraea* and it increased by 29% on hornbeem, *Carpinus betulus*. Decline in relative growth rate was more on yellow birch, *Betula allegheniens* compared to gray birch, *Betula populifolia*. The pupal mass declined by 38% under elevated CO_2 on gray birch while there was no effect on pupal mass on yellow birch. The differential response was attributed to greater decline in nutritional quality of yellow birch than gray birch. The studies conducted with forest tent caterpillar, *M. disstria* indicate that larval feeding varies with host plant. Faster development time and 20% decrease in growth rate was observed on quaking aspen. Larvae preferred aspen to paper birch under elevated CO_2 conditions. No effect on the performance of the larvae was noticed on quaking aspen and white oak, *Quercus alba*. Slower larval growth, increased lipid concentration and higher number of ovaries were observed in small heath, *Coenonympha pamphilus* feeding on grasses. Increased consumption by common blue butterfly, *Polyommatus icarus* larvae, shorter development time and increased pupal weight were noticed when feeding on birdsfoot trefoil, *Lotus corniculatus*. Increased consumption by *Spodoptera* sps was observed on mungbean, *Vigna radiata* , upland cotton, *Gossypium hirsutum* and tall fescue, *Festuca arundinacea* . Greater larval survival on common beet, *Beta vulgaris* , longer development time on upland cotton (Table 1)

ii) Homoptera

The family aphididae in this order was widely studied, and mixed response of aphids was reported under elevated CO_2. As is evident from Table1 Cotton aphid, *Aphis gossypii* fecundity significantly increased on cotton . Local populations of grain aphid, *Sitobion avenae* on spring wheat, *Triticum avenae* and green peach aphid, *Myzus persicae* on annual blue grass, *Poa annua* increased under elevated CO_2 . *Myzus persicae* population on bittersweet (*Solanum dulcamara*) increased by 120% . Spittle bug (*Neophilaenus lineatus*) nymphal population was reduced by 20% and delayed development when they were fed with elevated CO_2 grown heath rush (*Juncus squarrosus*). Among five aphid-plant interactions tested there was no effect of elevated CO_2 on three aphid-host plant interactions. *Aphis nerii* on common milkweed (*Asclepias syriaca*), *Aphis oenotherae* on common evening primose (*Oenothera biennis*) and *Aulacorthum solani* on white shooting star (*Nicotiana sylvestris*).

iii) Other Orders

Red headed pine sawfly (*Neodiprion lecontei*) belonging to order hymenoptera when reared on elevated CO_2 grown loblolly pine (*Pinus taeda*) showed increased consumption, increased N utilization efficiency and overall larval growth . Decreased consumption and assimilation, 15 times slower growth of cranefly (*Tipula abdominalis*) belonging to order diptera on elevated CO_2 grown quaking aspen was observed. Chrysanthemum leafminer (*Chromatomyia syngenesiae*) grown on common sowthistle (*Sonchus oleraceus*) developed slowly and had low pupal weight . In order Thysanoptera, thrips (*Frankliniella occidentalis*) density decreased, consumption increased and leaf area damage increased by 33% on elevated CO_2 grown common milkweed as shown in Table 1.

II) Direct effects

Insects have been shown to respond directly to carbon dioxide concentrations. Wireworm larvae can locate a food source from distances of up to 20 cm and respond to a CO_2 concentration increase as small as 0.002% . The ability to locate host plants of some herbivores may be affected. Fluctuations in CO_2 density as small as 0.14% or 0.5 ppm were detected by the labial palps of *Helicoverpa* *armigera* . Other insects are able to locate their plant hosts following the plume of slightly higher CO_2 concentrations, as does the moth *Cactoblastis cactorum* (Bergoth) with its host plant *Opuntia stricta* . *Diabrotica virgifera virgifera* (Le Conte) uses CO_2 concentrations in soil to locate corn roots.

Effect of elevated temperature

a) Plants

The consequence of rising atmospheric carbon dioxide would be an increase in ambient temperature. But they are usually treated separately because of experimental difficulties of varying both independently (Whittaker, 1999). However, there are a small number of studies in which both temperature and elevated carbon dioxide were considered.

Elevated temperature is known to alter the phytochemistry of the host plants and affect the insect growth and development directly or indirectly through effect on host plants. The effect of temperature on different host plants is reviewed hereunder.

Differential response was noticed due to elevation of temperature in different species. Temperature caused a decrease in foliar nitrogen in *Q. robur* , increased in *Cardamine hirsuta*, *Poa annua*, *Senecio vulgaris* and *Spergula arvensis* and had no effect on red maple, *A. rubrum* and sugar maple, *A. saccharum* . The concentrations of Cinnamoylquinic acids decreased and Salidroside decreased in white birch, *Betula pendula* leaves under elevated temperature conditions . Leaf water content of sugar maple leaves declined and condensed tannin content increased in *Q. robur* .

b) Herbivorous insects

Temperature is identified as dominant abiotic factor directly affecting herbivorous insects. Temperature directly affects the development, survival and abundance of insects. The influence of elevated temperature on various insect species is presented below.

There was no effect of elevated temperature except early pupation on larvae of winter moth, *Operophtera brumata* feeding on oak leaves, *Q. robur*. Larval development and adult fecundity of *O.brumata* was adversely affected by increased temperatures on *Q. robur* . The long-term exposure to a 3.5°C increase in temperature shortened insect development but had no effect on pupal weight.. The larvae reared on elevated CO_2 grown leaves had reduced growth . Development time of the beetles *Octotoma championi* and *Octotoma scabripennis* feeding on *Lantana camara* was accelerated by approximately 10-13 days at the higher temperature. There was substantial mortality of the larvae under high temperature/ambient CO_2 treatment due to premature leaf loss by *L. camara* . The temperature enhancement increased the relative growth rate (RGR) of the larvae of chrysomelid beetle, *Phratora vitellinae* feeding on *S. myrsinifolia*.

The impact of elevated CO_2 on the phytochemistry of the plants was well documented. The results indicated that most of the studies have been concentrated on the array of plant species. In elevaqted CO_2 conditions across types of plants was significant. In majority cases decrease in nitrogen, increase in condensed tannins, tremulacin levels, starch, drymatter production and root shot ratiowas observed. The changes in phytochemistry of plants lead to deterioration of nutritional quality of plants.

The majority of the insects studied have been Lepidopterans, which are represented by only nine families. Of these economically important noctuidae have received the most attention. Most other orders are represented by only one or two species, nearly all of which are economically important agricultural pests. Remarkably, only three species in two families have been examined in the largest order, the coleoptera, and Diptera is represented by just two species in two families. The above review information on effect of elevated CO_2 on insect pests revealed that the performance of the same insect varied from host to host-indicating host species specificity. The effect of elevated

CO_2 was significant across various species of lepidopterans. The response of insects varied differently and was not consistently across host plants.(eg. The effects of elevated CO_2 on gypsy moth) while the response of different insects feeding on same host was different (eg. Differential response of insect feeding on Birch tree). The information on the response (increase, decrease and no effect) on the population size of the aphids was observed due to elevated CO_2.

The following points are noteworthy.

It was observed that majority of insect-plant interactions are from forest trees and grasses. Few studies are available on cultivated plants. There are no studies on important global pest like *Helicoverpa armigera* which is ubiquitous pest of international importance.

Herbivores respond to increased levels of CO_2 by increasing their food consumption, prolonging development time, and reducing their growth rates and food conversion efficiency . Changes in the performance of herbivorous insects, usually in the larval stages are correlated with changes in the quality of the food plants such as nitrogen level, C:N ratio, concentration of phenolics. In general, host plant quality declines in elevated CO_2 with leaf nitrogen decreasing and phenolics increasing. Changes in nitrogen content are correlated with changes in food consumption and changes in phenolics with changes in food digestibility. Leaf chewers (14 species) are generally able to compensate for quality of food by increased food consumption (30%) without adverse effects on pupal weight. Leaf miners (4 species) also increase food consumption but insufficiently to prevent a decline in pupal weight. Sap feeders (11 species) are the only functional group to show positive responses to elevated CO_2. Geographic distribution of insects will be affected by shifts in host-plant ranges. Scenarios like local extinctions, changes in endangered species status and altered pest status can be predicted. Plants and insects exposed to modified environmental conditions may lead to considerable advances in understanding the mechanisms of responses by both insects and plants; they do not necessarily predict the outcome of such interactions in real ecological changes in the open field, where expected change in plant-insect interactions may be buffered by many unknown interactions and other factors.

Experiments were conducted at CRIDA to study the effects of elevated CO_2 on insect pests of castor. The experimental results show that larvae of both the insect pest species viz., *Achaea janata* and *Spodoptera litura* consumed significantly higher quantity of castor foliage obtained from plants raised under elevated CO_2 conditions than the chamber and open ambient. The final larval dry weights were also higher on elevated CO_2 foliage. The effects of CO_2 on insect performance indices significantly varied across CO_2 concentrations. Higher significant approximate digestibility (AD) foliage and of relative consumption rate (RCR) were observed on elevated CO_2 foliage. Lower efficiency of conversion digested food (ECD), efficiency of conversion ingested food (ECI) and relative growth rate (RGR) of larvae were noticed on elevated CO_2 foliage than chamber and open ambient foliages. The estimated exponential trend equations of growth rate of both species of larvae indicated that larvae consumed slowly on elevated CO_2 foliage as noticed by lower coefficients with an increase of two days larval duration than those of chamber and open ambient. Changes in *A.janata* and *S.litura* growth rates can be attributed to variation in food processing efficiencies. Foliage of castor plants grown under elevated CO_2 was found to be nutritionally poorer with lower N concentration, higher C, C/N ratio and ployphenols (TAE). It can be seen that consumption and larval weights were positively related with carbon, TAE and C: N ratio and negatively with nitrogen content of leaves. The sequential sum of squares associated with each of the independent variables indicated that nitrogen is more important in determining consumption and weight gain of the larvae. Nitrogen was found to contribute to 75 to 96 per cent of the explained variation.

Table 1: Impact of elevated CO_2 on insect-plant interactions

Insect		Family	Host plant		CO2 conc. ppm	Effect on host plants	Impact on insects	Reference
Common name	Scientific name		Common name	Scientific name				
Lepidoptera								
Gypsy moth	*Lymantria dispar*	Lymantridae	Sessile Oak	*Quercus petraea*	530	42% increase in starch, decrease in N, increase in condensed tannins	Relative Growth Rate (RGR) reduced by 30%	Hattenschwiler and Schafellner, 2004
Gypsy moth	*Lymantria dispar*	Lymantridae	Sugar maple	*Acer saccharum*	300	Decreased N and C:N ratio	No effect on larvae	Williams *et al.*, 2000
Gypsy moth	*Lymantria dispar*	Lymantridae	Yellow Birch	*Betula allegheniens is*	700	Decrease in N Increase in condensed tannins from	No change in pupal mass Declined in relative growth rate more compared to gray birch	Traw *et al.*, 1996
Forest tent caterpillar	*Malacosoma distria*	Lasiocampidae	Quaking aspen	*Populus tremuloides*	560	Decreased N, Increased tremulacin levels	No effect on larval performance	Kopper and Lindroth, 2003
Forest tent caterpillar	*Malacosoma distria*	Lasiocampidae	Quaking aspen	*Populus tremuloides*	642	Decreased N, increased starch,	Fast development time, 20% lowered growth rate	Lindroth *et al.*, 1993
Small heath	*Coenonymph a pamphilus*	Satyridae	*Red fescue*	Festuca rubra	750	Decreased N, Increased C:N Ratio	Larval growth slower	Mevi-Schutz *et al.*, 2003
Small heath	*Coenonymph a pamphilus*	Satyridae	*Grasses*	*Brumus erectus Festuca spp Carex caryophylla*	600	Decreased N, Increased non structural carbohydrates and condensed tannins	Increased lipid concentration in adults, Higher no: of eggs in ovaries of females	Goverde *et al.*, 2002
Common blue butterfly	*Polyommatus icarus*	Lycaenidae	Birdsfoot trefoil	*Lotus corniculatus*	600	Decreased N, Increased C:N Ratio and sugar concentration	Marginal negative effect on larval mass gain	Goverde *et al.*, 2004
Common blue butterfly	*Polyommatus icarus*	Lycaenidae	Birdsfoot trefoil	*Lotus corniculatus*	700	Increased carbon based defense compounds	Greater pupal weight, shorter development time	Bazin *et al.*, 2002
Tobacco caterpillar	*Spodoptera litura*	Noctuidae	Mung bean	*Vigna radiata*	600	Decreased N, Increased starch and total soluble sugars	Increased feeding and growth rate	Srivastava *et al.*, 2002

Insect		Family	Host plant		CO2 conc. ppm	Effect on host plants	Impact on insects	Reference
Common name	**Scientific name**		**Common name**	**Scientific name**				
Beet armyworm	*Spodoptera exigua*	Noctuidae	Upland cotton	*Gossypium hirsutum*	900	Decreased N, Increased C:N Ratio	25% increase in consumption Longer development time	Coviella and Trumble, 2000
Thysanoptera								
Western Flower Thrips	*Frankliniella occidentalis*	Thripidae	Common milkweed	*Asclepias syriaca*	700	Decreased N, Increased C:N Ratio, Higher above ground biomass,	Density decreased, consumption increased and leaf area damaged increased by 33%	Hughes and Bazzaz, 1997
Coloeptera								
Green Leaf Weevil	*Phyllobius maculicornis*	Curculionidae	European white birch	Betula pendula	700	Decreased N, flavonyl glycosides Increased total phenolics, condensed tannins, (+)-catechin and cinnamoylquinic acids	Weevils preferred leaves grown under elevated co2 given a choice between treatments	Kuokkanen *et al*., 2003
Willow beetle	Phratora vitellinae	Chrysomelidae	Dark leaved willow	Salix myrsinifolia	700	Increase in stem, leaf total aerial biomass and specific leaf weight, decreased N and phenolics	Reduced relative growth rate of larvae, increased consumption	Veteli *et al*., 2002
Hymenoptera								
Red-headed pine sawfly	*Neodiprion lecontei*	Diprionidae	Loblolly pine	Pinus taeda	300	Decreased N, Increased starch, Decreased monoterpenes, High starch:N ratios,	Overall laval growth higher, corsumption lower	Williams *et al.,* 1997
Red-headed pine sawfly	*Neodiprion lecontei*	Diprionidae	Loblolly pine	*Pinus taeda*	650	Decreased N, Increased starch, High starch:N ratios,	Increased consumption, increase in N utilization efficiency	Williams *et al.,* 1994
Homoptera								
Cotton aphid	*Aphis gossypii*	Aphididae	Bt cotton	*Gossypium hirsutum*	1050	Increased C:N Ratio, Plant height, biomass and leaf area were higher	Aphid fecundity significantly increased	Chen *et al.,* 2005
Grain aphid	Sitobion avenae	Aphididae	Spring wheat	*Triticum aestivum*	750	Higher ear starch, sucrose, glucose, total nonstructural Carbohydrates, free amino acids and soluble protein, Decreased N	Local populations increased, Alate aphids on sticky traps decreased, alate forms deposited more aphids on plants	Chen *et al*., 2004

(Source: Srinivasa Rao et al 2006. Effects of elevated CO_2 and temperature on insect plant interactions–a review *Agricultural Reviews* 27: 200-207)