Cotton in the Climate Trap

EXPERT's Column

Dr K.R. Kranthi

(Dr. K.R. Kranthi, Director of Central Institute for Cotton Research (CICR), Nagpur has completed his Ph.D in Entomology from IARI, New Delhi. He has more than 20 years of experience in the field of cotton research.

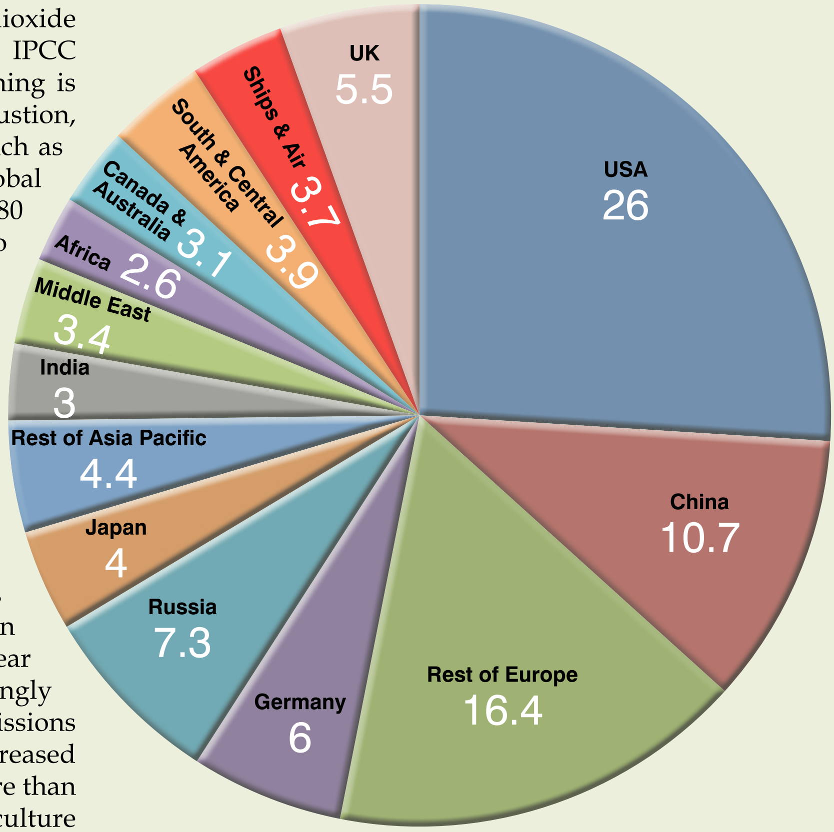
The views expressed in this column are his own and not that of Cotton Association of India)

Over the past few decades climate has become erratic. Even sceptics are now inclined to believe that 'climate change' effects are for real. Climate change can result in expansion of deserts, reduced glaciers ice and snow, severe droughts heavy rains, severe heat waves, ocean acidification, rise in sea levels, disturbed agricultural systems leading to reduced food production and loss of habitats, species extinction and loss of diversity.

Scientists believe that the greenhouse gases being produced by human activities are the main cause for global warming. There are four main greenhouse gases - water vapour, carbon-dioxide (CO_2), methane (CH_4) and ozone (O_3). The IPCC states that the largest driver of global warming is carbon dioxide emission from fossil fuel combustion, cement production, and land use changes such as deforestation. Studies show that the current global atmospheric concentration of CO_2 is about 380 ppm which is 100 ppm more as compared to pre-industrialisation. The IPCC and the Indian Institute of Science have now projected a figure of 575 ppm of CO_2 in the atmosphere by 2085. About 25% of green house gases are because of electricity and heat. Industry contributes 14.7% to greenhouse gases, about 14.0% to agriculture, 12.0% to land use change and the rest about 34% is due to transportation, industrial processes, fugitive emissions and waste. Alarmingly, recent reports showed that greenhouse gas emissions have increased by 2.2% per year between 2000 and 2010, compared with 1.3% per year from 1970 to 2000. Thus, there is a disturbingly increasing trend in the greenhouse gas emissions every year. The concentration of methane increased from 715 ppb in 1950 to 1800 ppb in 2011, more than an estimated 52% of it contributed by agriculture and animal husbandry.

The constant rise in temperatures and carbon-dioxide, erratic monsoon patterns, and constant increase in green house gases, are being recorded all across the globe. Since the early 20th century, the average temperature of the earth's climate system has increased by about 0.8°C. It has been observed that over the past 40 years, 90% of the global warming occurred in the oceans. A recent (2013) report of the Inter-governmental Panel on Climate Change (IPCC) predicts an increase of 1.1 to 2.9°C at low emissions and 2.4 to 6.4°C for high emission scenario, during the 21st century. Over two decades from 1990, the CO_2 emissions increased by 54% to 34.8 billion tonnes in 2011. The increase was 43% due to coal burning, 34% due to oil, 18% due to gas 4.9% due to cement and 0.7% due to gas flaring. The developed countries contribute most to CO_2 gas emissions and global warming. USA is responsible for 26% of CO_2 emissions, China contributes 10.7%, Germany 6.0%, UK 5.5%, rest of Europe 16.4%, Russia 7.3%, and Japan 4.0%. Other developing and under developed countries contribute less than 4.0% each.

Contribution of countries to CO_2 emission



Climate change and cotton

The cotton crop is sensitive to the climate induced effects and responds to soil, pests and diseases. Cotton crop production, processing and maintenance of clothes contribute to emission of greenhouse gases, but the contribution is less than 1.0% of the total. Irrigated cotton in developing countries is responsible for most of the CO_2 and N_2O emissions. Various sources estimated that for cotton cultivation, 1263 kg CO_2/ha is emitted due to chemical inputs, 642 kg CO_2/ha due to irrigation pump sets and 1800 kg N_2O/ha is emitted due to high inputs. But maximum greenhouse gas emissions are because of garment maintenance. The process of washing garments using detergents in washing machines and tumble drying consumes more energy and is responsible for higher CO_2 emission.

Climate change causes extreme fluctuations in temperature, rainfall, solar radiation and carbon-dioxide (CO_2) concentration. The climate changes influence crop growth, pathogens that cause diseases, and insects that occur in the cotton eco-system. Therefore, research on the influence of temperature, rainfall, radiation, CO_2 concentration, changes in soil moisture retention and nutrient holding capacity, on cotton production and productivity is important. However, some studies have shown that cotton crop in some regions may benefit from increased temperatures and carbon-dioxide. Cotton crop can tolerate higher temperatures and water stress to a great extent. Because of the tap root system, the cotton crop overcomes drought stress comfortably with subsequent availability of water. However, irrespective of any change in the CO_2 levels, yields are reduced if the crop suffers moisture stress at the time of flowering and boll formation. The Central Institute for Cotton Research has been working on projects that are focused on identification of adaptable cotton cultivars for increased CO_2 concentration, enhanced temperature, better drought tolerance characteristics and improved resistance to emerging pests and diseases, especially under elevated CO_2 levels.

Slightly high CO_2 levels enhance cotton yields

Cotton is a C-3 plant and is expected to respond positively to higher levels of CO_2. Cotton plants can utilise the elevated CO_2 levels when available in the atmosphere to produce larger leaves with greater surface area for enhanced photosynthetic activity to grow more vigorously. Elevated CO_2 levels can lead to more number of branches, more vegetation and more bolls. But, higher temperatures can cause boll shedding irrespective of the CO_2 levels. However, the vegetative and reproductive vigour of plants under elevated CO_2 levels can create higher demand for irrigation pesticides and fertilisers, in the absence of which yields could decline.

Pioneering studies were initiated at CICR (Dr Khader and team) in 1990, to study the impact of climate change on cotton physiology and productivity. The primary focus was to understand the effects of CO_2 at varying temperatures on various stages of the crop. Their research resulted in enhanced understanding on the following aspects. A number of positive effects on cotton plant growth were observed due to increased level of CO_2. Increasing CO_2 levels up to 650 ppm was found to be favourable for the cotton plants. Increasing CO_2 levels higher than 650 ppm was not favourable for cotton plant growth and productivity. However, plants maintained in elevated CO_2 level of 650 ppm only until squaring or flowering phase did not give full potential yield. Morphological, physiological and productivity attributes improved favourably in plants under elevated CO_2 level maintained until peak boll formation stage of the crop. The crop responded better to water stress and the fertilizer DAP (Di-ammonium phosphate) under elevated CO_2 conditions resulting in higher yields as compared to plants maintained at normal CO_2 conditions. Elevated CO_2 levels at 650 ppm also resulted in faster leaf expansion and increased photosynthetic rate that continued for a longer period. Maintenance of higher nitrate reductase activity in subtending leaf throughout the boll development period under elevated CO_2 levels was observed. Boll and boll components developed to the full extent under elevated CO_2 levels and took 10 days longer compared to the normal duration of 40–45 days under normal conditions.

Elevated CO_2 levels of 650 ppm and temperature of 40 degrees centigrade was found to be optimum for growth of cotton plants. Elevated levels of CO_2 significantly increased plant height, node number, sympodia number, leaf number, leaf area, dry matter production, reduced shedding of bud and bolls and delayed senescence of leaves. The total number of boll and weight increased significantly by 73% due to enhanced CO_2 levels, thus enhancing overall productivity of cotton. Interestingly, the fibre quality also improved significantly under elevated CO_2. The stomatal resistance decreased significantly and photosynthetic rate increased by 34-45%. Diurnal studies revealed that the nitrate reductase enzyme activity was inducted two hours earlier in plants grown under elevated CO_2 levels. Elevated CO_2 led to an increase in free amino acids in plants and a significant reduction in total and ortho-dihydric phenol content in the leaves. Cotton varieties irrespective of their origin from North, Central and South Zones responded to elevated CO_2 atmosphere significantly. LRK 516, H 777, LRA 5166 and CNH 38 gave more dry matter production under elevated CO_2 atmosphere than other varieties. Interestingly, the microbial population increased in soil under elevated CO_2 atmosphere. By and large, it appears that the impact of climate change on cotton production and productivity may be favourable in some parts of the country.

Impact on cotton insect pests, pathogens and weeds

Although it appears that cotton crop will do better in the changed atmospheric scenario at least during the later part of the 21st century, studies indicate that the pest problem will be aggravated further leading to an increased use of pesticides. In general, climate change is likely to affect agriculture very significantly through alteration or aggravation of biotic stress. Increase in temperature and carbon-dioxide can reduce the yields of many crops apart from increasing problems of insect and diseases. For example, studies at CICR showed that the leaf eating cotton caterpillar Spodoptera litura consumed 30% more leaves of cotton plants under elevated CO_2 compared to control plants, Further the insect laid more eggs after feeding on the CO_2 exposed plants.

The Inter-governmental Panel on Climate Change (IPCC) predicted that the global mean surface temperature may increase additionally from 1.4 to 5.8°C by 2100. The climate change, especially the temperature shift can have significant effects on each insect species specifically with reference to distribution and abundance and more importantly, could influence interactions between insect species within different ecosystems. Plant-insect interactions are key components of agriculture that attract frequent human interventions, which in turn have profound impact on greenhouse gas emissions and carbon sequestration. Studies conducted by several groups spread across the globe, suggest that insect abundance increases with rising temperatures and also indicate that temperature is the major factor in global climate change that directly affects insects that mainly feed on crop plants. Elevated global temperatures were found to create favourable conditions for the survival and reproduction of many insect pests such as the cotton sap-sucking pests whiteflies, thrips, aphids, mealybugs, etc. Among various sap-sucking pests the whitefly, B. tabaci B biotype causes serious yield losses to cotton, vegetable and ornamental crops not just as a direct pest but also as a vector of the cotton leaf curl virus in India and Pakistan. Elevated temperatures can have serious effects on increasing populations of the whitefly and the cotton leaf curl virus disease.

Insects are known for their high propensity for adaptability to changes in temperatures. The adaptation is not only related to adjustment in their body temperatures, but also adaptation to changed dietary environments. Elevated CO_2 in the atmosphere could result in increased ratio of carbon to nitrogen in leaf tissues which could decrease the nutritional value for insects. However, many insect species that thrive on cotton are known to be highly adaptive in nature to their dietary needs. The polyphagous insects that can eat on many plant species adjust rapidly to the changing diets, while insect that feed only on cotton plants and related species are already endowed with capacity to overcome many adverse effects, by entering into diapauses or adapting to the new nutritional status of the plants.

Some reports indicate that elevated CO_2 levels resulted in decline in the levels of Cry toxins in Bt cotton. Studies also showed that higher temperatures resulted in a decline in the efficacy of insecticides such as the synthetic pyrethroids and Spinosad.

Many pathogen species can adapt very easily to the changes in environment. Many diseases which are less severe now because of less favourable ecosystems, could find the changed environment more favourable.

Theoretically, since cotton plants are C-3 type and majority of weeds are C-4 type, the cotton crop can compete more effectively to dominate over weeds. However, some weed species may be endowed with higher diversity and better capacity for ecological adaptation as compared to crop plants, which would give them a selective advantage over the crop. Some tropical weed species could also adapt competitively to the changes in environment and become more detrimental.

Cotton in North India likely to be more vulnerable

Climate change can severely reduce the water availability in many countries, especially due to reduction in glaciers. Irrigation during the crucial reproductive phase enhances cotton yields. Irrigation sources of northern India and Pakistan are derived from the glaciers of Himalayas and the Tibetan plateau. There are several studies and simulation models that predict reduction in snow and ice in the mountains. Mountain glaciers and snow cover have declined in both the hemispheres contributing to a rise in sea levels. It has been reported that the elevated temperatures during the past few years have reduced the 30 km long Gangothri glaciers that feed the perennial Ganges. Thus the quality of water and the amount of irrigation water available for cotton could be negatively affected. Since timely irrigation is one of the crucial factors for high yields, problems with irrigation sources can be critical for productivity. Several changes in the overall monsoon patterns have been observed over the past few decades in various parts of India. Higher rainfall intensity was recorded in the west coast, Telangana region and North India contrasting with decrease of rainfall intensity in northeast India, Kerala and some parts of Gujarat and Madhya Pradesh which had 6-8% less rainfall than normal over a 100 year period. A technical paper 'Cotton and climate change - Impacts and options -to mitigate and adapt' published by the International

Trade Centre in 2011 indicates that the Sabarmati and Luni river basins, which cover about a quarter of Gujarat and 60% of Rajasthan, are likely to experience acute water scarcity conditions, and the Mahi, Pennar, Sabarmati and Tapi river basins constant water scarcity. The Cauvery, Ganga, Narmada and Krishna river basins are likely to experience seasonal or regular water-stressed conditions. The Godavari, Brahmani and Mahanadi river basins are projected to experience water shortages only in a few locations (India, 2004).

Cotton needs 100-120 days of soil moisture for proper growth. In general, about 600-700 mm rainfall in rainfed regions facilitates proper crop growth. The initial growth and peak vegetative phase need 2-3 mm water per day, while the flowering and boll formation phase need more water at 5-7 mm per day. Abnormal weather conditions may lead to shedding of fruiting parts, but the plants start recovering to produce a fresh flush. Some varieties are endowed with more regenerative capacity and high yields can be obtained through compensative mechanisms. Plant breeding efforts would be needed to identify varieties with such recuperative capacity to adapt to climate change.

Slightly warm conditions are better suited for sowing, early plant growth and bud formation. As the plant enters the reproductive phase, warmer conditions are more suited with positive effects on yields. However, boll retention, boll size and maturation are sensitive to higher temperatures. Increase in temperatures during peak boll formation and boll maturation leads to boll shedding. In general, a range of 20-40°C, that starts with the low temperature regime at sowing, increase in temperature during peak vegetative and early reproductive phase, to culminate at low temperature during boll formation is best suited for high productivity. Any major shifts in temperature during the crop growth phase can have negative effects on the yield. Higher temperature may lead to a longer growing season. Sowing in north India takes place during hot conditions. The subsequent high temperatures lead to a longer growing season, often resulting in sterility and poor boll formation due to higher temperatures. However, studies also show that higher temperatures could also increase micronaire, fibre maturity and strength. It is important to initiate plant breeding efforts to develop varieties that produce good quality fibre and that can tolerate high temperatures in such regions.

The vulnerability of cotton in north India also extends to the possibility of higher levels of whitefly infestation and whitefly transmission of the leaf curl virus disease due to increase in temperature. Central and South India could be less affected by climate change because of the diversity of cropping systems prevalent in the region as compared to the lesser crop diversity of North India. Thus North India could be more vulnerable to climate change compared to rest of the country.

Mitigating the effects of climate change and global warming

There are concerns in scientific and academic circles to find ways to mitigate the ill effects of climate change. Most importantly, there are two kinds of questions. One – is it really possible to slow down the effects through proactive plans? Second – is it possible to develop adaptive systems, crop and animal varieties that can still be equally productive despite the climate change?

The first plan to slow down effects of climate change, will eventually depend on the developing countries which may have to find ways to reduce the greenhouse gas emissions. The second alternative to develop mitigation measures can help only to a certain extent. It is now clear that organic systems can help immensely in reducing CO_2 emissions, but these are technically highly demanding and need robust scientific technologies to obtain higher yields. The methane and nitrous oxide emissions can be reduced by reorienting crop production systems towards optimisation of inputs, input application methods and also placing more emphasis on the utilisation of bio-fuels and enhancing the organic component in crop nutrition, and pest management. Energy efficient technologies and renewable energy sources should be identified and promoted.

Some measures to reduce greenhouse gas emissions:

- Adopt conservation agriculture, minimum tillage and appropriate soil conservation practices to prevent soil erosion and consequent loss of soil organic matter. Develop crop residue management practices and strictly avoid burning of crop residues. Simple technologies such as maintaining soil covers also enhance soil carbon sequestration
- Strengthen organic agriculture practices wherever possible. Develop efficient organic alternatives to minimise chemical inputs in the cotton ecosystem. Develop cultural practices to minimise pest and disease infestation. Develop diversity in cropping systems should be established in all the regions that are more vulnerable to climate change.
- Develop robust varieties that are resilient to biotic and abiotic stress factors related to climate change.
- Develop cotton production systems with emphasis on low inputs and high productivity in rainfed regions. Optimise irrigation and synthetic chemical inputs to prevent wastage. Reduce the irrigated area under cotton and develop robust varieties for rainfed regions