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Climate change, its impact and mitigation strategies for sugarcane production: A review

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Abstract
The effects of climate change have reached such an extent that irreversible changes in the functioning of the planet are feared. Changes in climate can be expected to have significant impacts upon crop yields through changes in both temperature and moisture. Climate change has exerted significant impact on sugarcane productivity due to changes in temperature, CO_2 level, precipitation etc. Increasing temperature will also increase the production of sugarcane crop by addition in stem juice, photosynthesis, leaf area and total biomass, since, it is a C_4 plant having high photosynthetic efficiency. However, erratic rainfall will decrease the productivity of sugarcane as grand growth phase is mainly affected by the monsoon. However, through adjusting the planting dates according to the atmospheric conditions, choosing more efficient methods of planting and irrigation, following management practices like growing drought and high temperature tolerant varieties and mulch application etc. will enhance the sugarcane yield, helps in better adapting and reducing the impact of climate change.

Keywords: Climate change, sugarcane, temperature, productivity

Introduction

Climate change, in reference to, Inter-Governmental Panel on Climate Change (IPCC), refers to any change in climate over time, whether due to natural variability or as a consequence of any human activity (Anonymous, 2007) [1]. For the past some decades, the gaseous composition of earth's atmosphere is undergoing a significant change, largely through increased emissions from energy, industry and agriculture sectors; widespread deforestation as well as fast changes in land use and land management practices. These anthropogenic activities are resulting in an increased emission of radioactive gases, *viz*. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), popularly known as the 'greenhouse gases' (GHGs). These GHGs trap the outgoing infrared radiations from the earth's surface and thus raise the temperature of the atmosphere. The global mean annual temperature at the end of the 20th century, as a result of GHG accumulation in the atmosphere, has increased by 0.4–0.7 ºC, above that recorded at the end of the 19th century. The Inter-Governmental Panel on Climate Change has projected the temperature increase to be between 1.1 °C and 6.4 °C by the end of the 21st Century (IPCC, 2007). The global warming is expected to lead to other regional and global changes in the climate-related parameters such as rainfall, soil moisture, and sea level. Snow cover is also reported to be gradually decreasing.

A natural feature of our climate system is 'greenhouse effect'. Without the atmosphere, the earth's average temperature would be approximately 33°C colder than is observed currently. The atmosphere is very efficient in absorbing long-wave radiation, which is then emitted both upward toward space and downward toward the earth and the latter emission serves to heat the earth further. This further warming by reradiated long-wave radiation from the atmosphere is called as the greenhouse effect. While, same gases in the atmosphere are particularly good at absorbing the long-wave radiation and those are known as the greenhouse gases (GHG). Apart from this, an increase in the earth's temperature is caused by human activities such as burning coal, oil and natural gas that releases harmful green house gases into the atmosphere which forms a blanket around the earth, trapping heat and raising temperatures on the ground. This led to steadily change in our climate (Varshneya, 2009) [3].

The effects of climate change have reached such an extent that irreversible changes in the functioning of the planet are feared. Some of the main effects of climate change with specific reference to agriculture and food production especially during the last decade are: increased occurrence of storms and floods; increase in incidence and severity of droughts and forest fires; steady spreading out of frost-free intervals and potential growing season; increased frequency of diseases and insect pest attacks; and consistently vanishing habitats of plants and animals.

steady spreading out of frost-free intervals and potential growing season; increased frequency of diseases and insect pest attacks; and consistently vanishing habitats of plants and animals. It is important for the international scientific community to use all accessible knowledge to stop or reverse this trend to the maximum extent possible. Future impacts of climate change will affect in a broad way to human and natural systems, with consequences for human health, food and fiber production, water supplies, and many other areas which are vital with respect to economic and social well being. Although, carbon dioxide emissions from agriculture are small but many other important GHGs are emitted from agriculture as well and it accounts for about 60% of all nitrous oxide, mainly from fertilizer use and approximately 50% of methane, mainly from natural and cultivated wetlands and through enteric fermentation by cattles. Methane and nitrous oxide emissions are projected to further increase from 35 to 60% by 2030, driven by growing nitrogen fertilizer use and increased livestock production in response to growing food demand. Changes in climate can be expected to have significant impacts upon crop yields through changes in both temperature and moisture (Venkateswarlu and Shanker, 2009) [4].

Therefore, concrete efforts are required for mitigation and adaptation to reduce the vulnerability of agriculture to the adverse impacts of climate change and making it more resilient. The adaptive capacity of poor farmers is limited because of subsistence agriculture and low level of formal education. Therefore, simple, economically viable and culturally acceptable adaptation strategies have to be developed and implemented. Furthermore, the transfer of knowledge as well as access to social, economic, institutional, and technical resources need to be provided and integrated within the existing resources of farmers.

According to (IPCC, 2014), climate change refers to change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties that persists for an extended period whereas, climate variability is variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. As per (IPCC, 2013), climate change has resulted in rising temperature, changes in the water cycle, erratic precipitation patterns and increase of extreme weather events. Since last 50 years, the frequency of cold days/nights and frosts have decreased however; hot days/nights, heat waves, heavy precipitation events have become more frequent. The decreased annual rainfall trend has been experienced in the northeastern and northern regions of China, Northeastern India, Indonesia, coastal Pakistan and Philippines. On the other hand, damage from intense cyclones is likely to be increased in the Cambodia, China, India, Iran, Philippines, Vietnam and over Tibetan Plateau. Since 1850 on the earth surface, each of last three decades was successively warmer than any preceding decade. In the northern hemisphere, 30 year period from 1983 to 2012 were warmest since 1400 years.

Research study conducted by Kothawale *et al.*, 2012; Jain and Kumar 2012; Jain *et al.*, 2013; Oza and Kishtawal (2015) [7, 8, 9, 10] concluded that in India, the trend of warming and changes in the patterns of temperature and rainfall would affect differently in different parts of the country. According to Mall *et al*., (2016) [16], for example, parts of western Rajasthan, southern Gujarat, Madhya Pradesh, Maharashtra, northern Karnataka, northern Andhra Pradesh and southern Bihar are highly vulnerable for extreme weather events. Global climate change exerts a strong effect on local climate structure and patterns, as does climate variability (e.g. the El Niño events occurring over the last 3 decades of the 20th century caused floods, droughts and heat waves). On the other hand, conditions in the Sudan-Sahelian region of Nigeria have settled into a situation of relative drought persistence. Coupled with increase in temperature and evaporation, this is likely to lower crop yields and thus significantly affect the sugarcane industry in Nigeria.

Studies shows that large variation has been noticed over the small regional scale within Punjab state. At Ludhiana and Patiala districts in Punjab during *Rabi* season, maximum temperature has been increased by 0.02 and 0.04 °C /year whereas, the minimum temperature was increased at the rate of 0.06 and 0.01 °C/ year, respectively. Since last four decades, the rate of increase in minimum temperature was 0.02, 0.07 and 0.02°C /year in the districts of Bathinda, Ludhiana and Patiala, respectively (Kaur and Kaur, 2015) [12] whereas, decreasing annual rainfall trend was recorded at Ballowal Saunkhri and Bathinda districts of Punjab (Gill *et al.*, 2010) [13].

(Porter and Gawith, 1999 and Tubiello *et al.* 2000) [14, 15] explained that owing to the global warming, increased temperature may decrease the length of the growing season for crops that would reduce the yield of many crops and shift in the area of cultivation. The considerable reduction in the length of growing period of *Kharif* and *Rabi* seasons has been also observed. Auffhammer *et al.*, 2012 [16] studied that water requirement of crops also expected to increase with projected warming and extreme events whereas, drought is affecting agriculture more than extreme rainfall events.

Evidence of climate change in India (Earth System Science Organization [ESSO]- 2017)

- Annual mean, maximum and minimum temperatures increased over the country as a whole show significant warming trend of 0.16, 0.17 and 0.14 °C per decade, respectively, since 1981.
- The number of warm days and warm nights has significantly increased over the last 35 years.
- The total number of consecutive dry days with spell length more than five days has increased significantly, while the total number of consecutive wet days has shown significant decrease.

Future climate change projections over the Indian region (ESSO- 2017)

- The all India mean surface air temperature change for the near-term period 2016–2045 relative to 1976–2005 is projected to be in the range of 1.08 °C to 1.44°C
- The all India mean surface air temperature is projected to increase in the far future (2066–2095) by 1.35 ± 0.23°C under RCP (Representative Concentration Pathway**)**.
- Although the all India annual precipitation is found to increase as temperature increases but precipitation changes throughout the 21 Century remain highly uncertain.

Climate change in Punjab

- Gradually increasing minimum temperature (about 0.4 to 1.6 °C) over the past 30 years at Ludhiana, Punjab has been witnessed (Prabhjyot- Kaur and Hundal, 2010) [18].
- A 5-year mean of annual rainfall variability analysis in Punjab revealed that rainfall decreased significantly

during the last five decades at the rate of 5.5, 3.4, 7.1, 4.3 and 5.5 mm per year at Amritsar, Gurdaspur, Ferozepur, Bathinda and Sangrur, respectively, and rainfall increased significantly at 1.4 mm per year during past 108 years at Ludhiana.

- The average maximum temperature decreased by -0.32°C during the 41 year period at the rate of -0.02°C annually and the annual average minimum temperature decreased by -0.8°C during the same period at the rate of -0.1°C annually in Amritsar. The annual average rainfall increased in Amritsar by +150 mm between 1949 and 2000, indicating increase of +3.7 mm per year. Maximum and minimum temperatures in the Punjab region have increased by 0.5-1.0°C and by 0.5 to 1.5°C respectively in 2010 with respect to the base line 1971-2000 (Kaur *et al.*, 2011) [19].

Crop-weather relationship of sugarcane

Sugarcane crop requires various climatic conditions throughout its long life cycle, the crop needs long duration of bright sunshine, high temperature with optimum rainfall and high relative humidity are suitable for good growth, larger height and higher cane yield at formative stage whereas, at ripening phase clear weather without rainfall, warm days and dry weather conditions are ideal. In this way, sugarcane growth and yield is more dependent on weather parameters (Kushwaha and Pal, 2000) [20]. Not like the various crops grown in India, which are distinguished by their biotic and abiotic characteristics, the productivity of sugarcane also depends upon different weather optimums.

The optimum climatic conditions for sugarcane differs from stage to stage of the crop. It is very much depends on the volume and period of precipitation, moisture, relative humidity, temperature and soil conditions (Gawander, 2007) [6]. Mall *et al.*, (2016) [11] reported that the during the duration of major phases of plant growth, i.e. germination phase (0-60 DAP), formative phase (60-130 DAP), grand growth phase (130-250 DAP) and maturity phase of sugarcane crop, the maximum, minimum temperature and relative humidity plays an important role. Best temperature range for sprouting of sugarcane setts is 20-30°C (Srivastava and Rai, 2012). On the other hand, for best seed germination, it ranges between 11°C to 42°C, the optimum temperatures for maximum growth take place between 27°C and 36 °C (Pierre *et al.*, 2014) [23] and temperature and solar radiation plays major role at tillering phase, while, number of tillers are influenced by water availability, spacing between both plants and rows, manuring, control of weeds and other management practices.

Optimum growth and development of sugarcane crop depends mostly upon the prevailing weather conditions especially temperature. Bonnett *et al.*, (2006) [24] studied the effects of high temperatures (above 32 °C) on the growth and carbon division of sugar cane at the University of Queensland (Australia). They collected, 7-month-old crops of Q117 and Q158 varieties, which were exposed to 2 month treatment while the crops were permitted to develop as a ratoon plant for 6 months in another study. The greater temperature in both tests led in more but smaller internodes.

In the higher temperature treatment, most plant internodes had reduced sucrose material than lower temperature internodes. The internodes from the crops at the greater temperature on a dry mass particulary had significantly more hexoses and fiber but reduced sucrose. Persistent base temperature of 8 °C was beneficial for all the physiological processes and phenological stages of sugarcane crop in United Kingdom (O'Callaghan *et al.*, 1994) [25] and in an another experiment conducted at South Africa showed that optimum base temperature for leaf appearance was 10 °C and for tiller appearance was 16 °C (Inman-Bamber, 1994) [26]. However, ideal temperature conditions ranges between 30 to 35 °C during germination phase of crop (Ingamells, 1989) [27]. On the other hand, it was found that 32 to 38 °C was optimum for crop (Binbol *et al.*, 2006) [28]. He also reported temperature below 21 °C retards the growth but 20-30 °C range found to be favourable for germination of cane setts under Indian conditions (Srivastava and Rai, 2012). Natural sugarcane ripening happens during the phase of maturity which needs low temperature. However, nitrogen deficiency associated with low temperature and mild water stress are some ripening agents (Alexander, 1973) [29].

Scarpari and Beauclair (2004, 2009) [30, 31] also claimed that temperatures below 20°C are best for ripening because low temperatures lower sugar cane growth rates and accelerate stalk sucrose accumulation. However, elevated temperature increases the transformation of sucrose into fructose and glucose. The seeds of sugarcane crop are known as fluff and Pierre *et al.*, (2014) [23] observed ideal temperature for germination of seed ranges between 27 to 36 °C. According to the Mall *et al.*, (2016) [11] alterations in maximum and minimum atmospheric temperature has considerable impact on certain phenological stages of sugarcane crop such as germination, tillering, peak growth and ripening stage. At tillering stage, temperature plays significant role but, the water availability, spacing, fertilization, weed management and other agronomic practices considerably influence the number of tillers.

According to Rupkumar and Subbaramayya (1980) [32], sugarcane requires temperatures between 30 and 35°C for maximum number of tillers. At the maximum and minimum temperature, respectively around 40°C and 10°C, limits cane development. (Kumar, 1984) [33] suggested that the temperature and humidity for the duration of first three months of sugarcane (germination to tillering stages) have greater impact on the yield. The upward thrust in temperature and drier climate pre-requisites at same time are beneficial for maximum yields. Similarly, during the formative stage, temperature and solar radiation are important. Internode elongation phase required temperature between 18-19°C (Bacchi and Souza, 1978) [34]. As the rate of vegetative growth decreases and the amount of sucrose in the cane increases when the temperature ranges from 12 to 14 °C. Alternatively, the mean minimum temperature of 20 °C was congenial at the active development stage (Fageria *et al.*, 2010) [35]. Clowes and Breakwell (1998) [37] indicated that elevated temperature promotes the flowering of sugar cane. Shanmugavadivu and Gururaja Rao (2009) [36] claimed that the decrease in clonal flowering ability in traditional breeding is due to the high temperature environments before and throughout the initiation period and the absence of precipitation. Maximum temperatures are combined with clear skies, dry climate, and low moisture, resulting in water deficiency and hampering flowering water stress. High temperatures also decrease frost frequency and severity (Mathieson, 2007) [38]. Although the accumulation of sugar also reduces with elevated photorespiration (Binbol *et al.*, 2006 and Gawander, 2007) [58, 21]. Temperature range between 8 and 34°C immediately improves the photosynthetic efficiency of sugarcane (Gawander, 2007) [21]. Peak temperature more than usual was appropriate and dangerous for the subsequent phases up to the fifth month of sugarcane cultivation. The intense favourable and negative responses are + 4 percent in the third month and -6 per cent in the fifth month, respectively (Kumar, 1984) [33]. Additionally, sugarcane quality also decrease with frost impact (Clowes and Breakwell, 1998) [37] and frost also impacts the seriousness of insect pests, illnesses, and weeds in sugarcane crops (Neumeister, 2010) [39]. High temperature may also increase the potential for evapotranspiration of sugarcane canopy rapid development. An experiment on temperature-affected physiological parameters at the University of Bayreuth, Germany was conducted. They growed sugarcane crops at different temperatures (15, 27 and 45 °C) for a period of 10 months. Results showed that sugarcane growth was limited in subtropical regions by adequate cooling winds of 15 °C, although elevated temperatures had less influence. Plants grown at 27 °C were higher than plants grown at 15 °C or 45 °C under all circumstances. The rate of photosynthesis of sugarcane crops grown at 45 °C was higher than those grown at 15 °C when the plants were 3 months old (Fabio *et al.,* 2013) [40].

Mitigation and adaptation strategies

The adaptation strategies should focus special attention on technologies and management regimes that will enhance sugarcane tolerance to warmer temperatures during winter and especially the harvesting phases. Thus, development of the stress tolerant and high-yielding sugarcane cultivars is one of the important strategies in adaptation of climate change. Sugarcane breeders and other scientists can develop computer data base to design hybridization (within or between species) for special requirement in the breeding programs, use growth and physiological traits to screen elite clones for resistance/tolerance to biotic and abiotic stresses (Inman-Bamber *et al*., 2012) [41], and use tissue culture, molecular biology, and gene transformation technologies to improve breeding and selection efficiencies. Studies have shown that some genotypes/cultivars are better than others in tolerance to water deficit (Inman-Bamber *et al*., 2012 and Da Silva, 2012) [41, 46] and low temperature stresses, in radiation use efficiency, and in nutrient use efficiency.

Matthieson (2007) suggested that increasing the irrigation efficiency can be suitable options of adaptation under limited rainfall / water stress situation. Singh *et al.,* (2015) advocated to apply farm yard manure (FYM) in sugarcane to save 25% nitrogenous fertilizers without any negative effects on yield. Shahi (2002) described that in sub - tropical India, February and March is optimum time of sugarcane planting therefore, the late (April-May) planted sugarcane records 30-50 per cent yield reduction than normal sown crop.

During 2010-12 and 2011-13, Singh *et al.,* (2017) [45] showed result findings by performing with different sugarcane genotypes under different planting seasons at Faridkot, Punjab and reported that autumn sugarcane produced 19% more cane yield than spring and 46% than summer. The sugarcane yield may be enhanced by 10 to 53% only by planting the crop during February instead of April. They also suggested that genotypes CoJ 88 and CoJ 89 performed well in summer planting hence, these genotypes may be promoted for (April/May) planting after harvesting the wheat crop**.** Ability of sugarcane varieties to attain different stages differs from each other hence, for making the harvesting decisions varietal differences growth and maturity rates must be considered.

Sugarcane production could never be improved until and unless promising varieties and technologies are adopted on large scale. Similarly, higher cane yield is the function of higher genetic potential of a variety. Efforts are made to increase cane production by introducing high yielding varieties and adoption of improved crop production techniques. Therefore, development of new sugarcane cultivars that can contribute to adaptation to climate change (especially for elevated CO_2 and temperature) by discovering and introducing desirable genes for agronomic trait development (Menossi, 2008) [46] and using basic breeding, physiological screening (Inman-Bamber *et al*., 2012 and Zhao *et al.*, 2011) [41], and new technologies of molecular biology (Da Silva *et al*., 2013) [42] can mitigate the negative effect of climate change and improve sugarcane yields, productivity, and sustainability. Using technologies of molecular biology and gene transformation to develop Genetically Modified (GM) sugarcane varieties, such as herbicide glyphosate resistance, drought tolerance, high sugar content, and disease resistance, may be one of the important ways to mitigate negative impacts of environmental stresses due to climate change (Grice *et al.*, 2003 and Joyce *et al.*, 2013) [47, 48].

Besides breeding new varieties of sugarcane to mitigate effects of climate change, scientists can also use biotechnology to reduce abiotic and biotic stresses associated with sugarcane. Genetically modified sugarcane has a potential of increasing yield, drought tolerance and insect resistance of sugarcane. Biotechnology also releases varieties faster than conventional breeding of sugarcane. However, in Zimbabwe, the technology have not yet been accepted as there are concerns on health and environmental issues. Also biotechnology requires highly skilled researchers and capitol to procure the equipment to be used which may be limiting in Zimbabwe (Cheavegatti-Gianotto *et al*., 2011) [49].

Another adaptation strategy to low rainfall due to climate change is to invest in irrigation infrastructure like dams, canals and pumps (Matthieson, 2007 and Parry *et al*., 2004) [50]. However, investment in irrigation development will reduce the likely competition of water resource between sugarcane production and other sectors. Besides increasing irrigation infrastructure, it is essential to increase the efficiency of irrigation (Matthieson, 2007) by reducing losses of water through properly scheduling irrigation and investing in irrigation technologies like trickle irrigation. High irrigation efficiency will save water in the midst of low rainfall and also reduce cost of production when yields are expected to be low due to moisture stress.

Climate change is projected to result in floods in some areas over coming years. Since floods result in waterlogging conditions, salinity and raised water table, reducing yields significantly (Glaz *et al*., 2004) [51], it is therefore important to adapt sugarcane production to such conditions. Drainage systems in the fields that are likely to be affected (flat) areas may need to be installed. Once the drainage improves, excessive salts causing salinity can be leached by irrigation (Clowes and Breakwell, 1998) [37]. Varieties that adapt to waterlogging and saline conditions may be grown.

Besides mitigating the direct effects of climate change, cultural practices that intensify climate change may be reduced, for example, sugarcane burning prior to harvest. Sugarcane burning before harvesting, a common practise throughout world is important for removing leaves and insects to facilitate manual cutting of cane. However, Levine (2000) [52] argued that this practice releases greenhouse gases like carbon dioxide, methane, non-methane volatile organic compounds and nitrogen gases which increases effects of climate change. Alternatively, sugarcane can be harvested without burning as it was the practice until 1940s (De Resende *et al*., 2006) [53]. In order to complement harvesting without burning, self-trashing varieties may be adopted (Clowes and Breakwell, 1998) [37]. According to De Figueiredon and La Scala (2011) [54], conversion from burning to green harvest can increase the amount of sugarcane residue and this may have an impact on soil properties. Sugarcane residue is important in weed suppression, increases the content of organic matter in the soil which increases water holding capacity, improve soil structure and biological activity in the soil. However, no burning of sugarcane prior to harvesting have got its problems like reduced tillering, reduced available nitrogen during wetter years and increase in certain pests and diseases (Clowes and Breakwell, 1998) [37].

Another cultural practice that increases the effects of climate change is burning sugarcane trash. In Zimbabwe, after harvesting sugarcane, tops, burned and unburned leaves which make up trash is cleared from all ridges and placed in every eighth of the ridge in the field. This is done to allow free flow of irrigation and to reduce interference of trash with land preparation. This practice exacerbates the effects of climate change since burning trash releases greenhouse gases. Alternatively, trash may act as mulch and can be windrowed to control wind and water erosion (Clowes and Breakwell, 1998) [37]. Trash when decomposed may release essential nutrients like nitrogen that may be taken by the crop (Vallis *et al.*, 1996). Therefore, use of organic nitrogen sources like sugarcane residues can improve the nitrogen content of the soil. However, N present in sugarcane residues are released slowly (Vitti, 2003). Potentially, use of trash can reduce nitrogen requirement of the crop from inorganic sources. Use of high rates of inorganic nitrogen increases the effects of climate change (UNESCO and SCOPE, 2007). Also salinity is associated with use of high rates of inorganic nitrogen. Furthermore, in Zimbabwe, when sugarcane is ploughed out in preparation for a new crop, many operations which make up land preparation are involved. The operations may include pre-discing, ripping, ploughing, post-discing, land planning and ridging (Clowes and Breakwell, 1998) [37]. Many operations of land preparation usually result in more fuel being used. Using large quantities of such fuel releases more greenhouse gases that exacerbate the effects of climate change. Therefore it is vital, that operations for land preparation be kept at minimum. This also reduces the cost of production in the midst of sugarcane yield declining as projected by climate change. In addition, fossil fuel can be replaced by bio fuel to power transport vehicles in the sugarcane industry (Shumba *et al.*, 2011) [57].

Conclusion

Climate change has exerted significant impact on sugarcane productivity due to changes in temperature, CO_2 level, precipitation etc. Increasing temperature will also increase the production of sugarcane crop by addition in stem juice, photosynthesis, leaf area and total biomass. The increasing CO_2 content in future can benefit the cultivation of sugarcane crop, since, it is a C_4 plant having high photosynthetic efficiency. However, erratic rainfall will decrease the productivity of sugarcane as grand growth phase is mainly affected by the monsoon. Hence, by adopting suitable management strategies the negative impact of climate change can be controlled. Through adjusting the planting dates according to the atmospheric conditions, favourable environment can be provided for higher productivity. Choosing more efficient methods of planting and irrigation, according to different regions, can enhance the yield in future. Management practices like growing drought and high temperature tolerant varieties, and mulch application will also enhance the yield and helps in reducing the impact of climate change.

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