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Effect of climate change on sugarcane crop: A review

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Abstract
Sugarcane (*Saccharam offcinarum* L.) is a monocotyledon and perennial large grass belongs to family Gramineae (Poaceae). It is a C_4 agro-industrial crop cultivated broadly in two distinct agro-climatic regions known as tropical and sub-tropical in the world. It is a long duration crop and requires 10-15 and even 18 months to mature, depending upon the geographical condition. There are several factors which effect the sugarcane growth and development. Out of these factors, climate change is one which badly affects the crop. Climate change may influence the sugarcane crop in its favour or create stress condition. Among several climatic factors, rainfall and temperature is the major and comes under the most crucial weather parameters of sugarcane for its productivity. The increase in temperature and CO_2 is causing global warming and also leads to deficit in rainfall resulting decline in crop production. Therefore assessing the effect of climate change and its impact on crop growth is very important to harvest the maximum potential yield of all the varieties in future.

Keywords: sugarcane, climate change, impact and crop productivity.

1. Introduction

Sugarcane (*Saccharum officinarum* L.) is C_4 crop which assumes an important position in the Indian economy. It is an important cash crop of the country cultivated over about 5 million ha area including both sub-tropical and tropical regions. Sugarcane is a tall perennial plant growing erect up to 5-6 meters and produces multiple stems (canes). It has essentially four growth phases: Germination phase (up to 45 days after planting-DAP), Tillering phase (45-120 DAP), Grand growth phase (120-270 DAP), Maturity and Ripening phase (270-360 DAP) each with a specific climatic requirement (Moore and Frederik, 2014) [26]. Sugarcane grows well in those regions where the climate is more or less tropical. A mean temperature of 28-32°C is best suited for the growth of sugarcane. Higher temperature above 45°C reduces tillering of the crop and later on its growth, whereas temperatures below 20°C may slow down the growth. The areas with a minimum temperature <5°C are not suitable for sugarcane cultivation. A relative humidity of 70-85% during growth and 55-75% during ripening phase is ideal. Relative humidity < 50% during growing season is not suitable for sugarcane cultivation (Shukla *et al.* 2017) [37].

India is the second largest cane growing country followed by Brazil. Both Brazil and India accounts 53% of the global cane acreage in 2016-17. Uttar Pradesh contributes about 44% total sugarcane production of India (133.40 million tonnes), therefore it is the largest sugarcane growing state in India. Uttar Pradesh with the area of 21.60 lakh ha contributes 47.79% of total area of the country 2016-17 (Ram, 2017) [28]. Uttar Pradesh constitutes one of the most important sugar producing belts of the world, next to Sao Paulo (Brazil). This state has produced a total of 87.5 lakh tons sugar during 2016-17 (Singh and Ram, 2017) [33]. There are several climatic factors which are responsible for productivity either maximum or minimum of a variety as well as crop. The climatic change could affect agriculture in several ways such as in terms of productivity, growth rates, photosynthesis and transpiration rates and finally the quality and quantity of the product. Climate change is likely to directly impact food production across the globe. Increase in the mean seasonal temperature can reduce the duration of many crops and resulted in reduction of yield of related crops. There are several areas where temperatures are already close to the physiological maxima for crops, warming will impact yields potential with immediate effect (IPCC, 2007) [16]. Sugarcane is vulnerable to both direct and indirect effects of changes in temperature and rainfall. Since it is a long-duration crop (12-15 months) with variable sensitivity to weather at different growth stages, even a slight departure of the weather pattern from normal (long period average) during a year is liable to cause significant loss of sugarcane yield followed by sugar production (Glasziou *et al.* 1965 [12]; Mali *et al.* 2014 [24]; Zhao and Li, 2015 [41]). An age-old phenomenon, climate change can happen due to increasing population levels, innovation, high living standards, technological progress, industrialization, increasing infrastructure, reduction of trees, agricultural land and so many. Analysis of the long-term weather trend by the India Meteorological Department (IMD) has revealed an increase in mean minimum temperature in all the climatic regions of India (Rathore *et al.* 2013 [29]). The rainfall and temperature changes in UGP may cast negative impacts on dry matter and sugar accumulation in future. Under such a scenario, shift in planting, harvesting, and cane crushing periods may be imminently required. Among climatic factors, water availability and temperature regimes during the growing seasons play a major role in determining the yield and quality (sugar content) of sugarcane crop all over the world (Zhao and Li, 2015) [41]. According to the analysis and report of IPCC, (2013) [17] the level of greenhouse gases has surpassed the highest levels of concentrations on earth over the last 800,000 years. This greenhouse effect, in turn, is causing increased rainfall, irregular distribution of rainfall, frequent hot extremes, floods, droughts, cyclones and gradual recession of glaciers. For any agricultural commodity, variation in yield between years is related to growing-season weather. Weather condition directly influences insects, diseases and weeds, which in turn finally affect the agricultural production and productivity.

1. Climatic requirement for the growth of the sugarcane crop

1.1 Rainfall: Sugarcane requires 1500-2000mm/yr rainfall to produce 100 ton millable cane. Plant crop requires 88kg water/kg of cane and 884kg water/kg of sugar. In other term the average water requirement per hectare for entire sugar season for Uttar Pradesh is 57 lakh liters. Water requirement at different growth phases for sugarcane crop in subtropical zone is 17% at germination phase, 24% at tillering phase, 37% at grand growth phase and 22% at maturity phase. In tropical weather the water requirement is 12% at germination phase, 22% at tillering phase, 40% at grand growth phase and 26% at maturity phase. (Bhardwaj, 2013) [4]. The sugarcane crop requires optimum rains during the vegetative growth phase for the formation of thick and tall cane and requires less rain during the ripening time for good quality juice. The rainfall ranging from 1100-1500mm/yr is optimum for the higher cane yield whereas, it can be grown successfully on the lower levels even upto 600 mm annual rainfall (ICAR, 2000) [15].

1.2 Temperature: The optimum range of temperature varies for different stages of crop. The optimum temperature required for germination (sprouting) of cane sett is between 28º-32 ºC. Temperature above the 38 ºC reduces the germination and also effect the vegetative growth by reducing photosynthetic rates and increasing the respiration whereas below 32 ºC temperature reduce germination and resulting plant population for poor. The tillering phase between March and June is favoured with atmospheric temperatures range from 30º to 32 ºC. Ripening period, require low temperature in the range of 12º-14 ºC by which reduces vegetative growth rate and enrichment of sucrose in the cane. Temperature below 5 ºC and above 35 ºC is not favourable for young leaves and buds. The high temperature may enhance the abiotic diseases and leads to change the sucrose content into fructose and glucose high temperature increases the photorespiration due to which sugar accumulation is being reduced (Binbol *et al.* 2006 [2], Gawander, 2007 [11]). Temperatures below 19 ºC are conducive for sucrose accumulation, and the optimum temperature for sucrose accumulation lies between 12º and 14 ºC (Fageria *et al.* 2010) [9]. Sucrose accumulation has been reported to decline above 26.6 ºC (Clements, 1980) [6].

1.3 Sunlight: Sunlight intensity is very essential for grand growth (formative) stage of sugarcane and other of C_4 plants, which accelerates photosynthesis as well as stabilization ranges. Tillering of plant is severely affected during the cloudy and short days season while bright sunshine on average 7-9 hours is very favourable for the tillering, stalk formation and good growth of the crop (ICAR, 2000 [15]; Fageria *et al.* 2010 [9]). The proper spacing between row to row and plant to plant is required to provide the proper sunlight to the sugarcane crop which will directly affect the yield. In case of sugarcane the upper six leaves canopy intercept 70% of the sunlight radiation which reduces the photosynthesis rate of lower leaves due to mutual shading. The areas with short growing period benefits from closer spacing to intercept higher amount of solar radiation and thus get higher yields however, with long growing season, wider spacing is suggested to avoid mutual shading and mortality of tiller shoots. (Srivastava and Rai, 2012) [35].

1.4 Photosynthesis: The physiological mechanism of vegetative growth phases and reproductive growth phase of sugarcane crops are dependent upon photosynthesis, for which sunlight is required. The growth of sugarcane plants is directly correlated with conservation of radiant energy from the sun to the plants fibers and sugar. During the process, the first product of photosynthesis is four carbon sugar (C_4) which is fixed in the specialized cells of conductive tissue found in stem of the plant. The amount of carbon gain per day from photosynthesis is dependent on latitude and clouds covers.

1.5 Relative humidity and wind: Humidity and wind have comparatively less effect on sugarcane cultivation, however, affect to a large extent in case of extremes. 80-85% humidity and warm weather conditions favours the rapid growth of the cane. In ripening phase, a moderate humidity with limited water supply is favourable (SC, 2012) [30]. Similarly, wind has no harm to plant until it reaches to a velocity capable of breakage of cane or damage to leaves. The high velocity may be harmful in initial stage of plant growth. The long duration high velocity wind will result to loss of moisture. Broadly, two different sets of climatic parameters are required in the life cycle of the plant. Long duration of bright sunshine warm season with optimum rainfall and high humidity in growing phase favours rapid growth of plant as well as cane length with good yield. The ripening season which is a phase of sugar storage needs clear sky without precipitation, warm days and dry weather conditions with relative humidity of about 51%. During this phase, about 12% cane weight and

15% cane height are being attained (Srivastava and Rai, 2012) [35]. The evapotranspirational demand risk is very high during grand growth phase because the active growth and demand for water are met by frequent irrigation of the crop using surface water and groundwater resources. The cane elongation phase generally referred to as the grand growth phase of sugarcane spans over the months of July to September and coincides with the monsoon season. The phase is characterized by warm temperature (28-32 ºC) and high relative humidity (87%). Cane growth slows down after October, and ripening begins when the temperature falls below 19.4 ºC and relative humidity remains moderate (60-65%). The rapid build up of sucrose and its accumulation begin in October and continue till December. The climate during the maturity phase influences the final sugar output which is favoured under cold and dry weather with large diurnal variation in temperature and adequate soil moisture (Moore and Frederik, 2014) [26].

2. Variability in annual, decadal and normal rainfall trends

Meteorological analysis of last 60 years had been conducted to understand the variability in rainfall. Out of last 60 years, 26 years recorded an excess rainfall while 34 years recorded a below long-term average rainfall (1956-2015). The linear trend analysis of the average annual rainfall in 60 years showed a declining trend. The highest mean annual rainfall (1094.7mm) was recorded during the decade of 1966-1975 whereas the lowest average annual rainfall (748.9 mm) was recorded during the decade of 1986-1995. The pattern of annual rainfall showed that the frequency of mild to moderate droughts increased from 1986 onwards till 2015 and recorded continuous droughts except in 1988, 1991, 1996, 1998, 2008, 2009, 2011, and 2012. These years received the adequate rainfall in respect of sugarcane crop. The trends in annual and decadal rainfall variability establish that continuous failure of rainfall and increasing spells of drought are becoming increasingly precarious for sugarcane cultivation in UGP (Upper Gangetic Plain). (Verma *et al.* 2018) [39]. As sugarcane productivity in UGP depends on total water requirement of 1500-2000 mm (Srivastava *et al.* 2011 [34]; Samui *et al.* 2014 [31]), higher or lower precipitation conditions are bound to fluctuate cane and sugar yields in the zone (Verma *et al.* 2018) [39].

2.1 Seasonal rainfall variability

Seasonal rainfall has direct correlation for sugarcane productivity. The analysis of sixty years data established that there was a decline in total rainfall in all seasons resulting in an average annual rainfall deficiency of 205.3mm during 1986-2015. Rainfall decline during the summer, kharif and rabi seasons coincided with the germination, tillering, grand growth, and maturity phases of sugarcane. These growth phases play a key role in governing the cane and sugar yield attributes (Moore and Frederik, 2014) [26]. While soil moisture below 16% has been reported to affect the germination adversely, higher rainfall leads to formation of a hard crust on the soil surface and hampers the germination process. Rainfall at the time of planting has adverse effects on germination of cane setts (Binbol *et al.* 2006) [2] as dry weather is favorable for germination (Jika, 1997) [18]. Kumar (1984) [19] reported a yield decline in sugarcane due to rainfall during the germination phase. Summer season (March to May) rainfall amounting to 32.7 mm shall be helpful for inter-culture operations during the tillering phase. Rainfall decline during grand growth and maturity phases might become a major bottleneck for cane and sugar production in UGP affecting both farmers and mills in the zone (Shrivastava *et al.* 2016) [36]. The tillering phase however is favoured by rainfall (23.5mm), where underground branching from compact nodal joints of primary shoot occurs for providing the crop with appropriate number of stalks required for good yield. Mall and his co-workers (2016) [25] reported that under rainfall deficit conditions, tillering gets retarded and affects the final yields. (Verma *et al.* 2018) [39]. It has been reported that rainfall deficiency due to changing monsoon dynamics is not always the only reason of increasing drought risk. Cloud Cover trend and aerosol loading may also contribute to the drought risk of a region by interacting in a complex manner. It clearly indicated that rainfall deficiency due to changing monsoon dynamics is not always the primary reason of drought. Cloud Cover trend, aerosol loading may also Cloud cover, rainfall and aerosol dynamics are related in a complex manner and is one of the least investigated area (Eastman and Warren, 2013 [8]; Lal *et al.* 2013 [21]; Costantino and Breon, 2013 [7]; Gryspeerdt *et al.* 2014 [13]).

2.2 Monthly rainfall variability

The decline in rainfall was observed in monthly rainfall normal from 1985-2015 in all the months starting from March to November, whereas increased rainfall was observed in the months of January, February, and December as compared to the monthly rainfall normal of 1956-1985. A maximum decline in rainfall was noticed in the months of July (52.8mm), August (84.2mm), and September (54mm). The declining trends of rainfall during July, August, and September results to adverse impacts on the grand growth phase which starts after 120 days of planting and lasts up to 250-270 days in sugarcane (Mall *et al.* 2016) [25]. It is the most crucial phase of sugarcane for actual cane formation, dry matter accumulation, elongation, and finally yield of the crop. October, November, and December have ripening phase of sugarcane crop and lasts for about 250-360 days after planting, where rapid sucrose accumulation takes place and vegetative growth gets retarded. This growth phase of sugarcane requires cold and dry weather conditions than the grand growth phase to undergo sufficient disaccharide formation. Meteorological data during 1986 to 2015 revealed that the ripening phase of sugarcane in the sub-tropical India suffered from severe rainfall deficit. The adverse effects however might have been curtailed partially through adequate irrigation supplement or conserved soil moisture from the preceding GGP rainfall. (Verma *et al.* 2018) [39].

2.3 Weekly rainfall variability

The probability and pattern of weekly rainfall deficit and surplus is very useful for suitable crop planning including decisions about pre-sowing irrigation, time of planting, inter-culture, irrigation scheduling, fertilizer application, and use of plant protection chemicals. Weekly rainfall condition is also required for scheduling planning of cane harvest and raising of ratoon crop to obtain optimum sugar recovery. The rainfall analysis revealed occurrence of 70% of initial probability of a dry week from the 1st to the 25th week in the sub-tropical India. These SMWs (standard meteorological weeks) covered the germination and tillering phases of sugarcane and suggested greater relevance of external water application for sustaining the plant population of crop which determines the final crop stand. It is expected 65.0% rainfall to the total average of annual rainfall is usually received during the 26th to 37th SMWs (25th June to 16th September). The collection of surface runoff water during this excess rainfall period and its recycling for agricultural use during the subsequent dry period shall serve to reduce soil, water, and nutrient losses from the agricultural crop fields. But an increasing trend of delayed-onset, frequent, and longer monsoon breaks in SMWs 26-37 has been observed which results the excessive tiller mortality, poor growth of surviving tillers, and cane yield decline in the sub-tropical. It is well known that uptake of maximum nutrients by sugarcane crop is during the late tillering phase, therefore any deficite of water at this stage causes poor nutrient availability to plants and hampers the crop growth (Lobell and Gourdji 2012 [23]; Pathak *et al.* 2014 [27]). Meteorological data also indicates high probability of SMWs 42-52 going dry due to which moisture scarcity during the ripening phase and suggests the requirement of irrigation to sustain growth and sugar accumulation (Fageria *et al.* 2010 [9]; Verma *et al.* 2018 [39]).

2.4 Change in annual rainfall of UP

Agriculture scenario of the state is very much dependent on annual rainfall and rainfall distribution pattern. Even green revolution in the state is directly related to rain condition. Therefore knowledge of rainfall and its variation is the most important factor for agricultural production and management. Meteorological data of annual rainfall since 1981-2012 revealed a significant decreasing trend in total quantum of annual rainfall for Uttar Pradesh. A significant decline of 5% in annual rainfall was also observed after 1996 in Uttar Pradesh. The frequency of occurrence of annual rainfall below normal was found increased after 1990s. The quantum of rainfall below normal in most of the years clearly indicated that there is a need to climate resilient varieties and it will affect the disease incidence and pattern of different disease of sugarcane. Results revealed that the quantum of total rainfall was found increased by 10.8% from normal rainfall during the decade 1981-1990 while it decreased for the rest two decades, i.e., 1991-2000 and 2001-2010 by 3.6% and 8%, respectively. In case of monthly rainfall it was significantly decreased after 1996 for the months of post monsoon and winter seasons (October-February) while at par for the months of summer season except May when it increased as compared to the quantum of monthly rainfall before 1996. The quantum of monthly rainfall was found significantly decreased after 1996 for initial and last months of monsoon season, i.e., June and September while it increased for the middle months, i.e., July and August as compared to before 1996. (Kumar *et al.* 2018) [20].

3. Normal temperature variability

Meteorological data of last 60 year of normal annual maximum temperatures is found a decline by 0.4ºC and a rise by 0.21 ºC in annual mean minimum temperature during the latter period (1986-2015). Rising trend of annual minimum temperature and a decline in annual maximum temperature levels in various agro-climatic zones of India and also been reported by the IMD (Rathore *et al.* 2013) [29]. Change in normal T_{max} for different months shows the highest decline in January (-2.0 ºC), May (-0.9 ºC), and June (-0.8 ºC) whereas the monthly T_{max} recorded an increase in July, August, and September. This increased T_{max} coincided with a significant decline in rainfall during the monsoon season, when sugarcane crop is spanning through the grand growth stage. Although decline in T_{max} and rise in T_{min} during different SMWs do not exactly correspond to each other, net reduction in T_{max} coupled with rising T_{min} during SMWs 5-13 coincided with the main sugarcane planting season (spring planting) in the sub tropical. A decline in T_{max} and an increase in T_{min} again during SMWs 45-52 would effectively reduce the diurnal temperature variation needed for adequate sugar accumulation; hence, protection measures are required to be taken here too (Gawander, 2007) [11]; Verma *et al.* 2018 [39]).

4. Global change in temperature

The latest scientific assessment on the earth's climate system has reported changed on both global and regional scales since the pre-industrial era. Further evidence shows that most of the warming (of 0.1 ºC per decade) observed over the last 50 years is attributable by the human activities (Gautam *et al.* 2013) [10]. The Intergovernmental Panel on Climate Change (IPCC) reported that the global mean temperature may increase between 1.4 and 5.8 degree Celsius (ºC) by 2100 (Gautam *et al.* 2013) [10]. This unprecedented increase is expected to have severe impacts on the global hydrological system, ecosystems, sea level, crop production, crop protection, animal husbandry and related processes. The impact would be particularly severe in the tropical areas, which mainly consists of developing countries, including India. Climate change has been observed at both global and local scales (IPCC, 2007) [16].

5. Effect of green house gases

Increases in long-lived greenhouse gases carbon dioxide, methane, nitrous oxide, halocarbons, decreases in stratospheric ozone and increases in tropospheric ozone directly influence the weather condition. Apart from the above sulphate aerosols, nitrate aerosols, black carbon and organic matter from fossil fuel burning, biomass burning aerosols, mineral dust aerosols, land use change, clouds, solar variability, and stratospheric and tropospheric water vapour are also responsible for increase of green house gases. Indian agriculture is affected by an extreme weather event and questions whether human influences on the climate could be held responsible to some extent. Last few years have associated with many extreme events and are being linked to increasing greenhouse gases. These events include the prolonged drought in Australia, the extremely hot summer in Europe in 2003, the intense North Atlantic hurricane seasons of 2004 and 2005 and the extreme rainfall events in Mumbai, India in July 2005 and many others. The global warming is result of an increase in the concentration of "greenhouse" gases, such as carbon dioxide, methane and nitrous oxide. The fossil fuel combustion along with land use change is the main reason for the global increase of carbon dioxide concentration, while agriculture for methane and nitrous oxide (Cerri *et al.* 2007) [5]. The changes in temperature, rainfall and solar radiation patterns due to global warming will affect the sugarcane production in both positive and negative ways. (Srivastava and Rai, 2012) [35]. This greenhouse effect, in turn, is causing increased rainfall, frequent hot extremes, floods, droughts, cyclones and gradual recession of glaciers (IPCC, 2013) [17].

6. Effect of increase in CO_2 level

Climate change is likely to lead to a northern migration of weeds. Many weeds respond more positively to increasing CO_2 than most cash crops, particularly C_3 "invasive" weeds. Recent researchers suggests that glyphosate, the most widely used herbicide in the United States and several other countries loses its efficacy on weeds grown at the increased CO_2 levels likely in the coming decades. These shifting of weeds and its increase will hamper the productivity of all the crops. Many weeds, pests, and fungi thrive under warmer temperatures, wetter climates, and increased CO_2 levels. Currently, U.S. farmers spend more than $11 billion per year to fight weeds, which compete with crops for light, water, and nutrients (Hatfield *et al.* 2014) [14]. The ranges and distribution of weeds and pests are likely to increase with climate change. Though rising CO_2 can stimulate plant growth, it also reduces the nutritional value of most food crops. Rising levels of atmospheric carbon dioxide reduce the concentrations of protein and essential minerals in many plant species. (Ziska *et al.* 2014) [42].

7. Effect of extreme weather on the GDP/ Farmers

During the period 1900-2014, there was number of occasions in which large Indian population got affected from drought. Drought was found the biggest than any other natural disaster. Agriculture production in India is closely dependent to the condition of summer monsoon (June to September) which contributes about 75% of the annual precipitation. Therefore, the variability of monsoon rainfall is of great relevance as they have a direct impact on total food grain production. Extreme weather events are having significant impact on agriculture and food security which is the main source of income to a large section of the rural population in our country. The growing incidence and severity of droughts, floods, hailstorms and other extreme weather events severely affect the livelihood options for small-scale farmers. It is disturbing to note that India loses, annually, about 2% of its GDP and around 12 percent of central government revenues to natural disasters (Lester and Gurenko, 2003) [22]. The form, frequency and increasing intensity of extreme events like drought, heat waves or floods are largely attributed to changes happening in earth's climate. In addition, extreme weather events can potentially damage agricultural infrastructure, affect soil conditions, water resources, natural ecosystems and several others which directly affect the economy of the country as well as GDP. A study conducted by Venkateswarlu and Shanker (2012) [38], reported that the negative impacts of climate change will be more in rainfed agriculture due to variability in rainfall as well as reduction in number of rainy days, which will have greater implications for farmer's on choice of crops, varieties, and cropping pattern and systems rather than irrigated agriculture. Studies have also indicated that water requirement is estimated to increase by 10% for every 1 ºC rise in temperature which has serious implications on productivity and water use efficiency in several crops.

8. Effect of climate on disease development

Upper Gangetic plain agro-climatic zone (ACZ5) ACZ5 (mainly comprising of the Uttar Pradesh province of India) is traditionally the highest sugarcane producing state of India. The increasing cloudy weather and lack of direct solar radiation with increasing drought risk may have impact on the sugarcane productivity and disease-pest incidences. Quality degradation and yield reduction of sugarcane in ACZ5 over the last decade is a matter of concern. It was found that Pokkah Boeng of sugarcane (causal organism: *Fusarium moniliformae*) has become a major threat to sugarcane during the recent decade, showing an increasing trend of disease incidence and making most of the commercial cultivars susceptible (Vishwakarma *et al.* 2013) [40]. They also reported that the severity of the airborne disease Pokkah Boeng incidence increases manifold under cloudy weather and high humidity up to 70-80% with favourable temperature during the rainy season (June, July, August and September) in ACZ5. The unseasonal rain, changes in the relative humidity and heavy dew influence the micro climate of the crop which leads to unpredicted insect and disease incidences (Sharma *et al.* 2013) [32]. This is the most active growth period where about 80% of cane weight is attained. A shift to a higher thermal regime brought about by lack of rains during the elongation phase also affects the dynamics of disease and pest attacks, which influences the cane and sugar yield (Bhardwaj *et al.* 1981 [3]; Berding and Hurney, 2000 [1]).

9. Conclusion

The requirement of temperature, rainfall, evaporation, sunshine, and relative humidity for four different phases of sugarcane is different. Therefore assessing the effect of climate change and its impact on crop growth is very important to harvest the maximum yield in future. As rainfall and temperature are the most crucial weather parameters of sugarcane that governs its productivity. It has been observed that decline in rainfall by 205.3 mm during 1986-2015 against 1956-1985. Mean annual T_{max} decreased by 0.4 ºC while an increase in mean annual T_{min} by 0.21ºC was recorded for the corresponding period. Rainfall deficit of 21.25% in monsoon rains during July and September has also been found which coincides with the most critical growth stage of sugarcane. Increase in temperature during the cane elongation phase has also been noticed and followed by a non-conducive temperature change during the ripening phase. Therefore, soil fertility status, breeding for stress tolerance varieties, breeding for low input varieties, disease, and pest scenario would make an important future research priority under changing climate scenario. Several studies clearly indicated that sugarcane production will directly or indirectly affected by changes in climate conditions. Apart from all above, frequency and intensity of extreme weather events, especially drought is first and foremost need to address. In the line, the most negative effects of climate change on sugarcane production may be the greenhouse gases if the emissions still remain high. It is well established that sugarcane is a hardy crop and have potential to recover from minor stresses. Slide rise in temperature have found low effect on decline of yield of sugarcane but it will bring the changes in other factors like rainfall. Irregular distribution of rainfall may cause to flood or drought conditions, which have negative impact on sugarcane production. The sugar production in India was also decreased by 2 million tonnes for the year of 2015-16 due to poor rainfall (PSMA-2015). The formative and elongation phases of sugarcane growth have been identified as a critical water demand period. Therefore, water scarcity during these phases reduces the yield of crop up to any extent and productivity is greatly affected.

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