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Simulating the impact of climate change on sugarcane production in Punjab

HARPINDER SINGH[1], SUDHIR KUMAR MISHRA[1*], KULDEEP SINGH[1], KULVIR SINGH[1], R. K. PAL[2], K. K. GILL[3] and P. K. KINGRA[3]

[1]*PAU-Regional Research Station, Faridkot,* [2]*PAU-Regional Research Station, Bathinda, Punjab*
[3]*Dept of Climate Change and Agril Meteorology, Punjab Agricultural University, Ludhiana, India*
*Corresponding Author email: *sudhirmet@pau.edu*

ABSTRACT

The present study was performed at three diverse agro-climatic zones of Indian Punjab. A validated DSSAT-CANEGRO model was used to simulate the response of different climate change scenarios on cane yield of four sugarcane varieties (CoPb 91, CoJ 88, Co 118 and Co 238) for each zone. Results described that elevated and lowered minimum temperature upto 3.0°C may alter cane yield by -17.9 to 18.0 per cent. Similarly, ±3.0°C altered maximum temperature may change the cane yield by -17.6 to 17.5 per cent. The sugarcane yield may be decreased by 2.4 to 14.4 per cent, 3.3 to 17.6% and 0.3 to15.4 per cent with 2.5 to 15 per cent reduced solar radiation and increase in the same unit may enhance the yield by 1.9 to 9.0 per cent, 1.3 to 13.6 per cent and 2.0 to 12.3 per cent at Faridkot, Gurdaspur and Kapurthala, respectively. A±30 mm rainfall may change the cane yield by 9.2 to 18.0 % similarly, rise and fall in CO_2 by 5 to 30 ppm was able to increase and decrease the cane yield by 2.4- 22.6 and 3.5 - 27.8 per cent, at different regions. This study confirmed that for sugarcane cultivation in Punjab CoPb 91 should be preferred. However, CoJ 88 and Co 238 may suffer cane yield loss of 7.8 and 9.9 per cent respectively.

Key words: Cane yield, climate change, DSSAT-CANEGRO model, simulation, sugarcane

Sugarcane (*Saccharum spp.*) is one of the most significant sugar producing crops that contributes almost 78 per cent to the sugar base of the world. India is the second largest country in the production of sugarcane after Brazil. In India during 2016-17, sugarcane occupied approximately 4.52 million hectares area and produced 309.98 million tonnes canes with 686 q ha^{-1} yield. However, in Punjab, area under sugarcane cultivation was 92 thousand hectares, while average cane yield was 734 q ha^{-1} and sugar recovery was 9.78 per cent (Anon., 2017). The sugarcane crop passes through all distinguished seasons of a year therefore, it requires a wide range of weather conditions. Its major phenological stages *viz*, establishment and formative (tillering), elongation and peak growth, ripening and maturity coincide with summer, monsoon and winter season, respectively. For sugarcane crop, temperature range between 20 and 40°C, long duration (12 to 14 hours) of sunlight, high (above 70%) humidity and well-distributed rainfall up to 1500 mm are favorable. Physiologically, sugarcane is considered as a good converter of incident sunlight into the sugar. At the grand growth stage, this crop is able to produce approximately 500 $kgha^{-1}day^{-1}$dry matters (Srivastava and Rai, 2012).

The global CO_2 concentration has been projected to increase from 280 ppm during the year 1750 to above 550 ppm by 2050. Rise in the average temperature of earth's atmosphere owing to global warming is projected to continue with higher rate. By the end of 21^{st} century, global temperature is projected to increase by 4.0°C (IPCC, 2014). In India, mean temperature during *Kharif* (July to October) and *Rabi* (November to March) seasons is projected to increase by 1.7 and 3.2ºC, respectively, while the mean rainfall is likely to increase by 10 per cent till 2070 (Pathak *et al.*, 2012).

Climatic changes and harsh weather conditions contribute to decreased production of many crops including sugarcane. Although, agro-climatic environments of Punjab have enormous potential to boost up the production of sugarcane but, the spatio-temporal variation in climate parameters often leads to declining yields and sometimes severe crop failure. Kingra (2016a) reported non- significant variation during *Kharif* in Punjab (Ludhiana) for maximum temperature, but minimum temperature increased significantly (@ 0.06°C per year) whereas, sunshine hours exhibited decreasing (@ 0.02 hours per day) trend. However, during *Rabi* increase in minimum temperature was 0.06°C per year while, both the sunshine hours and the wind speed decreased by 0.03 hrs per day and 0.03 km per hour, respectively (Kingra, 2016b).

DSSAT-CANEGRO is a prominent model which is capable to simulate the growth of the canopy using the crop's energy equation by intercepting photosynthesis radiation. Already, CANEGRO model has been employed in several studies *viz*, simulating the growth and yield characters of different sugarcane cultivars (Singh *et al*., 2018) and assessing the response of sugarcane crop under different planting seasons (Mishra *et al*., 2017). But, study on the effects of climate change on sugarcane productivity is still limited, particularly in North –Western part of India. Therefore, aiming to assess the impacts of climate change on irrigated sugarcane in three distinct agro-climatic zones of Punjab, the present investigation was undertaken which may be helpful in sustaining the high sugarcane production in the state under varying environmental conditions.

MATERIALS AND METHODS

The present investigation was carried out with four sugarcane varieties (CoPb 91, CoJ 88, Co 118 and Co 238) at three locations representing three different agro-climatic regions of Punjab state (Table 1). At Faridkot, proportion of the sand, silt and clay in the upper (0-15 cm depth) layer was 76.0, 13.0 and 11.0 per cent whereas, for adjacent lower layer (15-30 cm depth) it was 65.8, 12.0 and 20.2 per cent, respectively. Soil texture of Gurdaspur was sandy loam in nature containing the sand, silt and clay in the proportion of 29.5, 51.3 and 9.2 per cent at 0-15 cm depth and 27.3, 53.5 and 9.2 per cent in lower layer (15-30 cm) depth. Similarly, the soil of Kapurthala was predominantly sandy loam that contained varying proportion of clay, loam and sand having 7.0 to 7.1 pH at upper and subsequent layers, respectively.

The long-term (2000-2017) sugarcane yield data of each district was obtained from statistical abstracts of Punjab. In case of missing data, the available data of the nearest district has been used. Similarly for corresponding period, daily maximum temperature (°C), minimum temperature (°C) and rainfall (mm) for each location were collected from India Meteorological Department, New Delhi. However, daily solar radiation data was computed following Hargreaves and Samani (1982) model.

The CANEGRO model validated by Singh *et al*. (2018) was used to simulate the growth, yield and yield attributing characters of different sugarcane varieties in different agro-climatic regions of Punjab under following climatic scenarios:

i) Maximum temperature (°C)
± 0.5, ± 1.0, ± 1.5, ± 2.0, ± 2.5, ± 3.0

ii) Minimum temperature (°C)
± 0.5, ± 1.0, ± 1.5, ± 2.0, ± 2.5, ± 3.0

iii) Amount of rainfall (mm)
± 5, ± 10, ± 15, ± 20, ± 25, ± 30

iv) Solar radiation (%)
± 2.5, ±5.0, ±7.5, ±10.0, ±12.5, ±15.0

v) Carbon dioxide concentration (ppm)
± 5, ± 10, ± 15, ± 20, ± 25

The reference or base yield of each variety was simulated for each location using seventeen years daily average weather data of the corresponding districts following Kalra (2008). To understand the impact of altered weather parameters upon production of sugarcane the DSSAT – CANEGRO model was run by altering only one component at a moment and keeping other factors constant. The simulated yield was thus regarded as a reference or base yield.

RESULTS AND DISCUSSION

Variation in weather conditions

The annual thermal conditions followed patterns as Faridkot (31.1°C) > Kapurthala (29.4°C) > Gurdaspur (27.1°C) whereas, the reverse trends in the rainfall was observed in three respective zones *i.e*., Gurdaspur (1065.3 mm) > Kapurthala (733.8 mm) > Faridkot (379.5 mm). Similarly, the maximum annual mean solar radiation at Faridkot (7.0 MJ m^{-2} day^{-1}) was closely followed by the Kapurthala (6.7 MJ m^{-2} day^{-1}) and Gurdaspur (6.2 MJ m^{-2} day^{-1}). The mean monthly variation in the weather conditions at Faridkot, Kapurthala and Gurdaspur during the study period is depicted in Fig. 1.

Table 1: Geographical information of study area

Station/ district	Latitude	Longitude	Altitude	Region	Agro climatic zone
Faridkot	30°40'N	74°45'E	204 m	South-western	Four
Gurdaspur	32°40' N	7540°' E	241 m	Undulating plain	Two
Kapurthala	31°38'N	75°35' E	252 m	Central	One

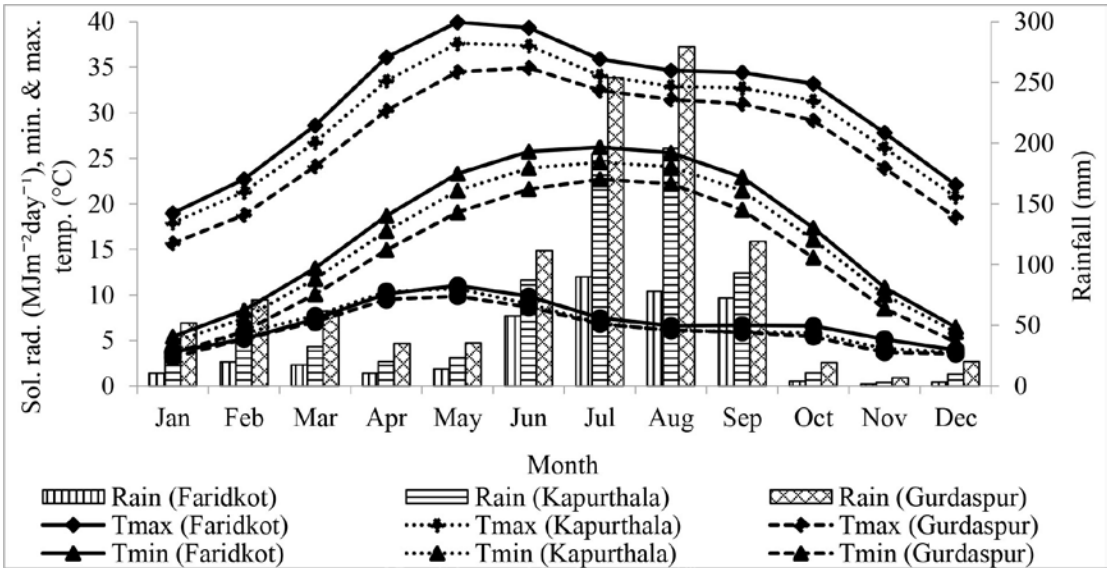

Fig. 1: Monthly weather conditions at different locations during 2000-2017

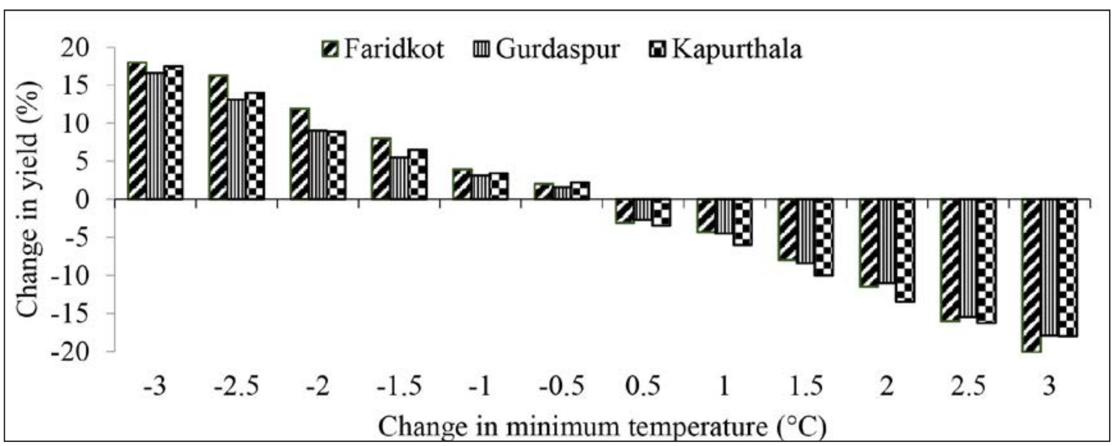

Fig. 2: Effect of altered minimum temperature on sugarcane yield at different locations

Effect of minimum temperature

Under Indian conditions, around 20-30°C temperature is considered optimum for sugarcane germination while 30 - 35°C is optimal range tillers production. However, mean minimum temperature of 20°C is congenial during active growth phase (Fageria *et al.*, 2010). The photosynthesis and respiration rates in plant are regulated by the environmental temperatures. Plants under lower night temperature respond into lower rate of respiration and thus high sugar yields conversely, under lower day temperature, plants experience low photosynthesis rate causing lower sugar yields. High night temperature negatively affect the dry weight production conversely, reduced air temperature can increase the sugar accumulation in cane stalks (Cardozo and Sentellhas, 2013). A 0.5°C decrease in minimum temperature was able to increase the cane yield by 2.0 per cent (1540 kg ha^{-1}) at Faridkot, 1.6 per cent (1434 kg ha^{-1}) at Gurdaspur and 2.2 per cent at Kapurthala (Fig. 2). At Faridkot, minimum temperature largely affected the cane yield than remaining two locations. With 3°C higher, minimum temperature, the cane yield may decline by 20.1 per cent

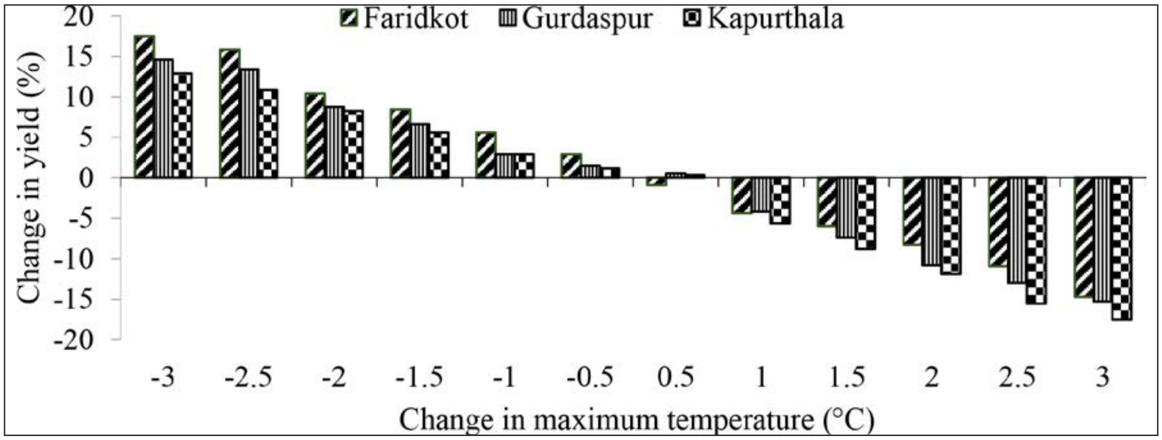

Fig. 3: Effect of altered maximum temperature on sugarcane yield at different locations

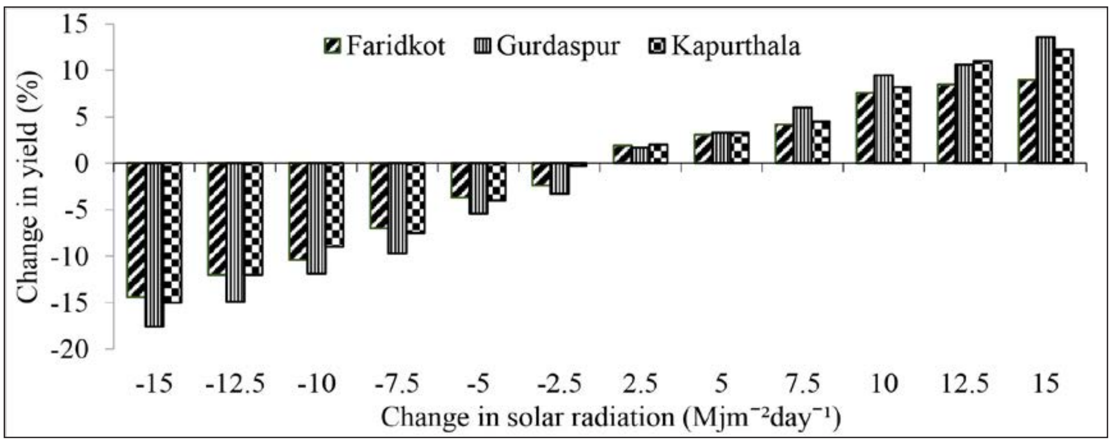

Fig. 4: Effect of altered solar radiation on sugarcane yield at different locations

at Faridkot, 18.0 per cent at Kapurthala and 17.9 per cent at Gurdaspur. Low annual total rainfall at Faridkot than Kapurthala and Gurdaspur may be the possible reason for aggravated impacts of night temperature at Faridkot. The decreasing scenarios of minimum temperature also had higher impact at Faridkot than remaining locations.

Effect of maximum temperature

The high temperature increase reversion of sucrose into fructose and glucose. Besides, sugar accumulation also reduces with high photorespiration and increase the potential evapotranspiration (Fabio *et al.*, 2013). At Faridkot, rise and fall of 0.5°C maximum temperature changed the sugarcane yield by -0.9 per cent (-693 kg ha^{-1}) and +2.9 per cent (+2233 kg ha^{-1}), respectively from reference yield. Similarly, ±1.0 and ±1.5°C of maximum temperature changed the yield by -3388 to 4312 kg ha^{-1} and - 4620 to 6468 kg ha^{-1} cane yield, respectively (Fig. 3). With 2.5°C decrease in maximum temperature, may get increase by 15.8 per cent (12166 kg ha^{-1}) yield while, 3.0°C decreased maximum temperature enhanced cane yield by 17.5 per cent (13475 kg ha^{-1}). Conversely, with increasing temperature by 2.0 to 3.0°C, the cane yield of Faridkot would be decreased by 6391 (-8.3%) to 11319 kg ha^{-1} (-14.7%). Likewise at Gurdaspur, ± 0.5°C change in the maximum temperature may affect the sugarcane productivity by 448 (0.5%) and 1344 kg ha^{-1} (1.5%), respectively. Hence, increasing temperature (0.5°C) would also have some positive effects on sugarcane yield under irrigated conditions (0.5°C) at Gurdaspur and Kapurthala. But, further rise in temperature by 1.0 and 1.5°C decreased the cane yield by 3763 and 6630 kg ha^{-1} accounting for 4.2 and 7.4 per cent, respectively. On decreasing same quantity (1.0 and 1.5°C) of maximum temperature, 2.9 to 6.6 per cent increased yield was obtained. Similarly, 2.0 to 2.5°C higher temperature would lead to a loss of 9677 to 11648 kg ha^{-1} sugarcane yield, respectively. On the other hand, reduction in temperature by 2.0 to 2.5°C

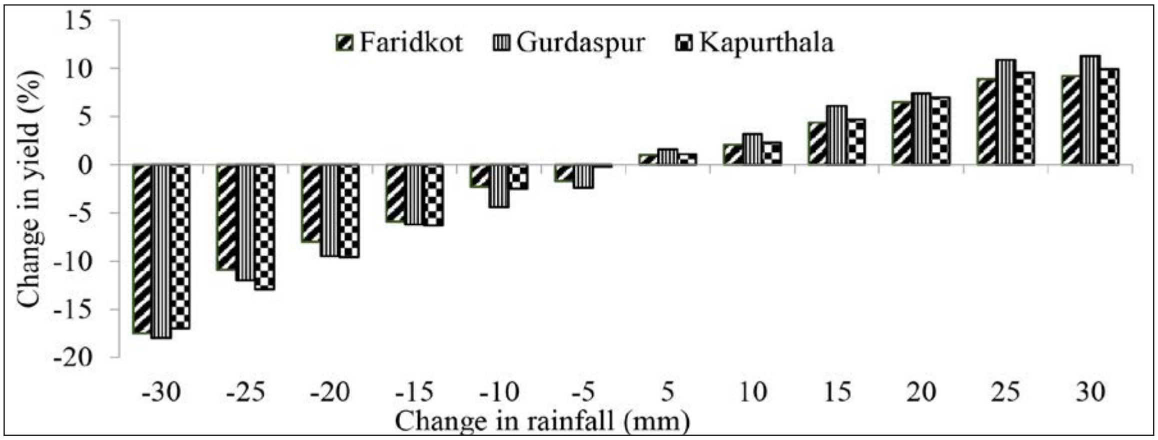

Fig. 5: Effect of altered rainfall on sugarcane yield at different locations

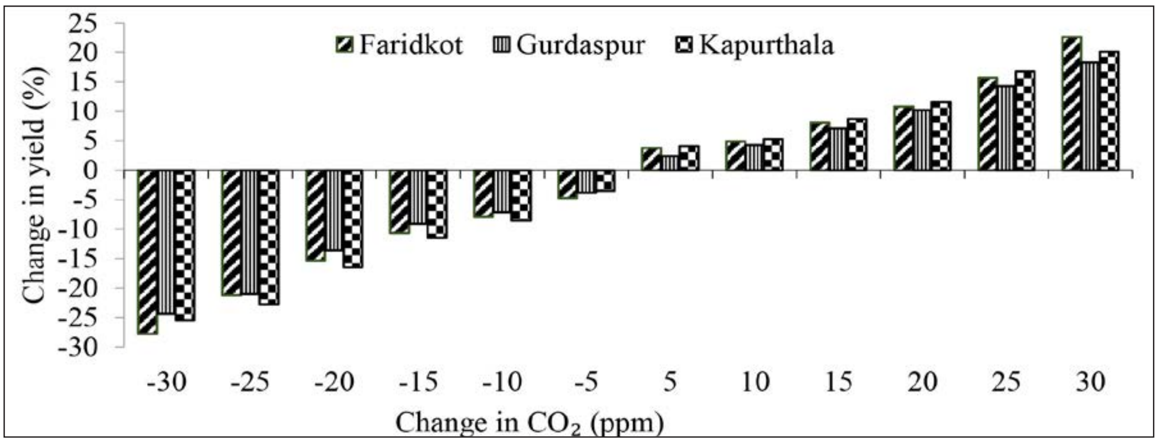

Fig. 6: Effect of altered CO_2 concentration on sugarcane yield at different locations

increased the cane yield by 8.7 (7795 kg ha^{-1}) to 13.4 per cent (12006 kg ha^{-1}). The altered maximum temperature by ±3.0°C declined the sugarcane yield by -15.3 to +14.6 per cent at Gurdaspur. At Kaputhala also 0.5°C increase of maximum temperature increased cane yield by of 0.3 per cent i.e., 248 kg ha^{-1} whereas, reduction in the maximum temperature have more profound positive impacts on the cane yield enhancement of 1.2 per cent (992 kg ha^{-1}). Contrarily, with raised temperature by 1.0, 2.0 and 3.0°C, correspondingly decline in the cane yield was 5.7, 11.9 and 17.6 per cent that is equivalent to the yield losses of 4670, 9835 and 14505 kg ha^{-1}, respectively. However, with fall in the respective unit of maximum temperatures, the simulated cane yield was 85047, 89427 and 93271 kg ha^{-1} and it was 2.9, 8.2 and 12.9 per cent higher than the reference yield (89600 kg ha^{-1}) of Kapurthala.

Effect of solar radiation

By governing the fundamental physiological processes such as photosynthesis and transpiration, the solar radiation determines crop development rate. Radiation use efficiency of the plant and ratoon sugarcane was 1.72 and 1.59 g MJ^{-1}, respectively (Robertson *et al.*, 1996). Sugarcane yield simultaneously increased with enhanced solar radiation and *vice-versa*. The increased sugarcane yield by 1.9, 1.7 and 2.0% was observed by 2.5% raise in solar radiation energy at Faridkot, Gurdaspur and Kapurthala whereas, cane yield losses of 2.4, 3.3 and 0.3 per cent were evident with the decrease of solar radiation by 2.5 MJ m^{-2}day^{-1}, at respective places. Even 5 to 7.5 per cent reduction of the solar radiation may result in the loss of sugarcane yield by 3.7 to 7.0 per cent. On the other hand, increment of the solar radiation by 10 to 15 per cent can increase the cane productivity by 7.6 and 9 per cent, respectively, at Faridkot. At Gurdaspur, a change in the sugarcane yield by -3.3, -5.4, -9.7, -11.9, 14.9 and -17.6 per cent has been simulated by the CANEGRO model with change in the solar radiation amount by -2.5, -5.0, -7.5, -10.0, 12.5 and -15 per cent, respectively. Similarly, the simulated cane yield of Gurdaspur (8960 kg ha^{-1}) may rise up to 9498 and 12186 kg ha^{-1}, provided the amount of the solar radiation is increased by 12.5 and 15.0 per cent, respectively. Unlike to the other locations, at Kapurthala also, 10 to 15 per cent reduced solar radiation produced 75212 to 70253 kg ha^{-1} cane yield which was - 9.0 to -15 per cent of the reference cane yield, contrarily, by increasing 10 to 15 per cent solar radiation, cane yield was increased by 8.2 to 12.3 per cent (6777 to 10125 kg ha^{-1}), respective (Fig. 4).

Effect of rainfall

Sugarcane being a long-lived crop requires more water eitherfrom rainfall or irrigation. The limited or no rainfall increases the crop water stress. Rainfall amount of 96 mm at formative stage and about 400 mm at early grand growth stage is ideal for optimum yield (Samui *et al.*, 2003). At Faridkot, higher rainfall by a 5 mm could enhance can yield by 1.0 per cent i.e., 770 kg ha^{-1}. Similarly, the high sugarcane productivity by 78617 kg ha^{-1} (2.1 % or 1617 kg ha^{-1}) and 80388 kg ha^{-1} (4.4 % or 3388 kg ha^{-1}) could be harvested with 10 and 15 mm higher rainfall. In this context, 25 and 30 mm high rainfall raised 8.9 % (6853 kg ha^{-1}) and 9.2 % (7084 kg ha^{-1}) cane yield, under Faridkot conditions. On the other hand, decreasing quantity of rainfall by 5, 10, 15, 20, 25 and 30 mm may decrease the sugarcane yield to the tune of 1.7 per cent (1309 kg ha^{-1}), 2.3 per cent (1771 kg ha^{-1}), 5.9 per cent (4543 kg ha^{-1}), 8.0 per cent (6160 k gha^{-1}),10.9 per cent (8393 kg ha^{-1}) and 17.5 per cent (13475 kg ha^{-1}), respectively. At Gurdaspur also, 10 to 15 mm increase in rainfall amount caused 3.2 per cent (2867 kg ha^{-1}) to 6.1 per cent (5466 kg ha^{-1}) rise in yield (Fig. 5). The cane yield was increased to the extent of 8512 to 10752 kg ha^{-1} (9.5 to 12 %), when rainfall was increased by 20 to 25 mm. Larger the departure of the rainfall quantity (30.0 mm), more would be the reduction in the cane yield (18%) in this region. At Kapurthala, 7934 (-9.6 %) to 10710 kg (-13 %) low yield may be experienced with 20 to 25 mm lower rainfall. Contrarily, 15, 20 and 25 mm increase in rainfall may increase the cane yield by 3885 (4.7%), 5786 (7.0%) and 7918 (9.6 %) kg ha^{-1}, respectively. The DSSAT CANEGRO model revealed that sugarcane yield is expected to be drastically reduced by 17 per cent (14051 kg ha^{-1}) with 30 mm shortfall of the rainfall. Conversely, 30 mm excessive rainfall amount have comparatively low significance *i.e.*, 9.9 per cent sugarcane yield enhancement. Therefore, it was clear from the analysis that the impact of the deficient rainfall on the crop production was more drastic However, beneficial effects of the increasing rainfall were relatively lower on the crop growth and productivity. Effect of the rainfall was more pronounced for the low rainfall regions like Faridkot as compared with the comparatively higher rainfall regions such as Gurdaspur and Kapurthala.

***Effect of* CO_2**

It is universally accepted that the atmospheric CO_2 has been increasing and the projected CO_2 concentration may reach 730–1020 ppm until 21st century (Solomon *et al.*, 2007). The increasing levels of CO_2ultimately increased production. At Faridkot, with decrease of 5 to 10 ppm CO_2, the cane yield may reduce from 77000 to 73381 kg ha^{-1} while, further decrease of 15 to 20 ppm CO_2, may reduce cane yield by 8239 to 11858 kg ha^{-1}. Whereas, an increase of 5, 10 and 15 ppm CO_2 produced higher cane yield by 79926, 80773 and 83237 $kgha^{-1}$. Similarly, the ± 30 ppm of CO_2 may change the cane yield by 22.6 to -27.8 per cent. At Gurdaspur, increase of 20, 25 and 30 ppm of CO_2 simulated the sugarcane yield by 98739, 102413 and 105997 kg ha^{-1} which was10.2, 14.3 and 18.3 per cent more than the reference cane yield. On the other hand, with decrease of 20, 25 and 30 ppm of CO_2 the simulated sugarcane yield was 77414 (-13.6 %), 70784 (-21 %) and 67738 kg ha^{-1} (-24.4 %), respectively (Fig. 6). Similarly, at Kapurthala also under different scenarios of the CO_2, the simulated cane yield by DSSAT CANEGRO model was changed from -3.5 to 4.1 per cent with ± 5 ppm, -8.5 to 5.3 per cent with ± 10 ppm, -11.5 to 8.7 per cent with ± 15 ppm, -16.5 to 11.6 per cent with ± 20 ppm, -22.8 to 16.8 per cent with ± 25 ppm and -25.5 to 20.1 per cent with ± 30 ppm.

CONCLUSION

The present study concluded that decrease in temperature considerably increased the cane yield while, increase in solar radiation, rainfall and CO_2 benefited the cane yield at different locations. The sugarcane cultivar CoPb 91 could be the first option, while Co 118 may be advised as second best option for sugarcane cultivation in the Punjab state. However, adoption of CoJ 88 and Co 238 may be opted with 7.8 and 9.9 per cent lowered cane yield. Rise in the minimum and maximum temperature by 3.0°C may decline the cane yield by 20.1, 18.0 and 17.9 per cent at Faridkot, Gurdaspur and Kapurthala, respectively. High rainfall by 30 mm may improve the cane yield by 9.2, 11.3 and 9.9 per cent at respective locations. Overall, climate change is expected to have severe detrimental effects on the cane yield that necessitates for investigating the location specific climate resilient adaptation technologies.

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REFERENCES

Anonymous (2017). Package of Practices for Rabi Crops Punjab Agricultural University Ludhiana pp. 59.

Cardozo N.P. and Sentelhas P.C. (2013). Climatic effects on sugarcane ripening under the influence of cultivars and crop age. *Scientia Agricola*., 70 (6): 449-456.

Fabio R.M., James W.J., Singels A., Royce F., Assad E.D., Giampaolo, Pellegrino Q. and Justino F. (2013). Climate change impacts on sugarcane attainable yield in southern Brazil. *Cli. change.,* 437-456.

Fageria N.K., Virupax C., Baligar C.A. and Jones J.W. (2010). Growth and mineral nutrition of field crops. 3rd Edn. CRC Press. Pp: 247-252.

Hargreaves G.H. and Samani Z.A. (1982). Estimating potential evapotranspiration. *J. Irrig. Drain. Eng. ASCE*., 108 (3): 223–230.

IPCC (2014). Climate Change: The Physical Science Basis. C*ontribution of Working Group I to the Sixth Assessment Report of IPCC*. Cambridge University Press, Cambridge, UK.

Kalra N. (2008). Effect of increasing temperature on yield of some winter crops in north west India. *Current Sci.*, 94 (1): 82-88.

Kingra P.K. (2016a). Climate variability and impact on productivity of rice in central Punjab. *J. Agrometeorol*., 18 (1): 146-148.

Kingra P.K. (2016b). Climate variability impacts on wheat productivity in central Punjab. *J. Agrometeorol*., 18 (1): 97-99.

Mishra S.K., Singh G. and Singh K. (2017). Sugarcane growth and yield simulation under varying planting dates in sub-tropical India. *J. Agrometeorol*., 19: 200-204.

Pathak H., Aggarwal P.K. and Singh S.D. (2012). Climate Change Impact, Adaptation and Mitigation in Agriculture: *Methodology for Assessment and Applications*. Indian Agricultural Research Institute, New Delhi. pp xix + 302.

Robertson M. J., Wood A.W. and Muchow R.C. (1996). Growth of sugarcane under high input conditions in tropical Australia. 1. Radiation use, biomass accumulation and partitioning. *Field Crops Res.*, 48: 11-25.

Samui R.P., John G. and Kulkarni M.B. (2003). Impact of weather on yield of sugarcane at different growth stages. *J. Agri. Physiol.*, 3: 119-125.

Singh J, Mishra S.K., Kingra P.K. Singh K. and Biswas B. (2018). Evaluation of DSSAT-CANEGRO model for phenology and yield attributes of sugarcane grown in different agroclimatic zones of Punjab, India. *J. Agrometeorol*., 20 (4): 280-285.

Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt K.B., Tignor M. and Miller H.L. (2007). Understanding and attributing climate change. *In Climate Change 2007*: The Physical Science Basis Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Cambridge University Press, Cambridge and New York.

Srivastava A.K. and Rai M.K. (2012). Review: Sugarcane production: Impact of climate change and its mitigation. *Biodiversitas*, 13 (4): 214-227.

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