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Can sugarcane cope with increasing atmospheric CO_2 concentration?

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Abstract

Climate change is the one of the most emerging problem of today's world. It is the most potent threat to the existence of mankind. These sudden abrupt changes in the climate are affecting all the crops to a great extent. High concentrations of CO_2 are one of the leading reasons contributing to climate change due to the increasing level of green-house gases. The elevation in CO_2 level is hampering crop production and productivity of different crops by causing effect on different physiological attributes. Unlike other crops, in sugarcane, several beneficial effects have been detected such as escalation in biomass, photosynthesis, leaf area, stalk juice volume, leaf dry weight and stem dry weight under such condition. Sugarcane crop is known to be one among those crops that is able to cope up with the increasing level of CO_2 due to four natural endowments it possesses. Very low carbon dioxide compensation point and unique property of sequestering carbon in form of *phytolith* or *planstone* is some of the important natural endowment with respect to the rising CO_2 concentration in atmosphere. Here, we have discussed the influence of atmospheric rising CO_2 concentration on sugarcane crop.

Keywords: C_4 photosynthesis; Carbon sequestration; CO_2; Climate change; Sugarcane.

Introduction

Changing climate is one of the most alarming global problems of the day (Shrivastava et al., 2016). A rise in CO_2 concentration in the atmosphere leads to escalation in temperature, affecting most of the physiological processes in plants. However, a mixed response, positive as well as negative, is exhibited by the plants under elevated CO_2 concentrations. It is being witnessed with increase in green-house gases (GHGs), temperatures, frequency of extreme events, drought, floods and rise in level of sea. GHGs are amongst the one which contributes to the climate change to a great extent. These include emission of CO_2, CH_4 and N_2O. Besides, some of the man-made gases like halocarbons, substances containing halogens like chlorine and bromine, sulphur hexafluoride, hydrofluorocarbons, perfluorocarbons are the other GHGs which have increased. Among all the GHGs, CO_2 is the most important one**.** As per Mauna Loa Observatory, Hawaii, the present carbon dioxide concentration in May 2018 was 409.23 ppm, however, the safe limit for this GHG was revealed to be 350 ppm that has been already attained in early 1988. Fossil fuel induced anthropogenic emissions due to industrial revolution is primarily responsible for the rapid increase in atmospheric CO_2 concentration. As per the Intergovernmental panel on climate change (IPCC) assessment, nearly half the anthropogenic CO_2 emissions have happened over the last forty years. Research showed that about half of CO_2 (and other emissions) does not accumulate in atmosphere rather it is absorbed by oceans (causing o*cean acidification*), rivers and lakes; and to a minor extent gets fixed (Shrivastava et al., 2016).

In this review, the effect of higher CO_2 concentration on sugarcane and how this crop manages the ever increase in atmospheric CO_2 concentration has been discussed.

Effect of elevated CO_2 concentration on sugarcane

Sugarcane is a recognized efficient crop in terms of sugar production and is affected by high CO_2 concentrations (Silva et al., 2008; Madan et al., 2014). However, this effect seems to be positive unlike in other crops (Fig. 1). Silva et al. (2008) had illustrated that under double CO_2 concentrations, sugarcane productivity was increased. Singels et al. (2014) had observed the influence of sugarcane growth and yield at three spots in Brazil, Australia and South Africa, using Canegro Model, at two different concentrations (360 ppm and 764 ppm). It has been found out that, increase in CO_2 concentrations will increase cane yield (+ 4 % for Ayr (Australia), to + 9 and + 20 % for Piracicaba and La Mercy regions, Brazil). High CO_2 concentration also causes an effect on morphological attributes of sugarcane crop. Vu and Allen

(2009) showed that in Florida, when CO_2 concentration was doubled then the leaf area, dry weight of leaf and stem and juice volume increased. A rise in temperature along with doubling of CO_2 concentration also witnessed the same pattern. Under such a situation, leaf area, leaf dry weight, stem dry weight and stalk juice volume was observed to be increased by 50 %, 26 %, 84 % and 124 %, respectively, as related to the cane grown at ambient temperatures and CO_2 (Vu and Allen, 2009). Furthermore, combination of double carbon dioxide concentration and high temperatures also leads to increase in soluble solids in stem, *viz*., ^{o}Brix by 2-3 folds (Vu and Allen, 2009). Similarly, fresh weight of cane stalk and fresh juice yield were also increased by 24 % when CO_2 concentration was raised from 350 ppm to 700 ppm (Madan et al. 2014). Vu et al. (2006) also showed similar results of increase in total above ground parts and fresh weight of stalk possessing young leaves by 44 % and 55.5 %, respectively, under raised CO_2 concentration. This might be because of increase in production and elongation of sugarcane plant cells (Pritchard et al., 1999) which might be related with the finding that under high CO_2 concentration, down-regulation of lignin related gene occurs leading to a higher XTH (Xyloglucan endotrans glucosylase/hydrolases) expression that suggested to result in more accumulation of sugars in sugarcane due to increase potential of expansion of its leaves (De Souza et al., 2008). Also, under elevated CO_2 concentration, internodes formation was favored more in sugarcane as reported by Madan et al. (2014). Additionally, under double CO_2 concentration, about 52 % increase in water use efficiency (WUE) was observed in its leaves which may be due to the increased assimilation rates and lower water loss efficiency (Vu et al., 2006). Also, elevation in CO_2 concentration causes increase in biomass production, especially in stem biomass; however, there were significant differences in comparison with the other crops grown under same situations (De Souza et al. 2008). Vu et al. (2006) had indicated that increase in nitrogen use efficiency, intake of light and water and high water use efficiency may be the reason behind the increase in biomass production under such a situation. Furthermore, increase or decrease in photosynthesis rate has been reported in such a situation. Studies have illustrated correlation of photosynthesis rate with the stomatal conductance (g_s), as increase in g_s is directly proportional to CO_2 intake that will lead to escalation in photosynthetic rate (Kusumi et al., 2012). In respect to sugarcane, escalation in photosynthesis under elevated CO_2 concentration has been known. Higher consumption of light and water along with increase in stomatal conductance under such a situation is the reason behind increase in photosynthesis rate (De Souza et al., 2008; Madan et al., 2014). Besides, Moore et al. (1998) had showed an association between acclimation of photosynthesis in sugarcane to elevated levels of acid invertase and leaf hexose/sucrose ratios under elevated CO_2 concentration. Once sugarcane plants were exposed to high CO_2 concentration for 22 weeks, there were lower acid invertase levels along with no difference in leaf hexose/sucrose ratios leading to no photosynthetic acclimation. Foyer (1987) had shown that this might be due to hindrance of export rate of carbohydrate of source organs to sink ones. This implies that lower invertase expression in sugarcane leaves leads to higher photosynthesis. This resulted in increase in transportation of sucrose in stems (Miyazaki et al., 2004). This implies that increase in CO_2 concentrations in future will show positive effect on sugarcane crop by increasing the diameter of cane and by reducing the use of water and better production of sucrose.

Besides the changing climate, increasing CO_2 also contribute to be one of the major cause of water stress due to which immense loss in crops production and productivity occur. A recent study showed that variation in regional areas imparts advantages on crop water productivity under increasing CO_2 scenario (Deryng et al., 2016). Marin et al. (2012) had revealed that large decrease in crop transpiration (- 11.0 and - 10.5 %) and evapo-transpiration (- 9.1 and - 8.9 %) in sugarcane occur at increasing CO_2 concentration at 750 ppm for Piracicaba and Ilha Solteira regions of Brazil, correspondingly. However, studies had also revealed that in other C_4 plants like sorghum (Ottman et al., 2001), maize (Leakey et al., 2006), C_4 grassland of Texa (Maherali et al., 2002) do not respond to increasing CO_2. Loss in organic matter in soil is also one of the contributors to increase in atmospheric CO_2 concentration. Agricultural soils are known to emit CO_2 and studies have reported that this is due to the association between soil attributes (physical, chemical and even biological) and the climate (Carvalho et al., 2010; Panaosso et al. 2011; Teixeira et al., 2011; Teixeira et al., 2013; Silva-Olaya et al., 2013; Bicalho et al,. 2014; Zhang et al., 2015). In this respect, in case of sugarcane crop grown areas, studies have also revealed positive results (Luca et al., 2008; Panosso et al., 2009; Figueiredo et al., 2010; Bicalho et al., 2014; Bahia et al., 2015). A recent study had reported that sugarcane crop cover and tillage at a minimum level forms a strong and efficient approach in mitigating the CO_2 emissions emitted from soil (Farhate et al., 2018). Moitinho et al. (2018) had revealed that different sugarcane cultivars respond differently for soil CO_2 emissions and one must keep in mind that prior to planting of sugarcane as a management tool for mitigating GHGs emission, one must look for the cultivar to be planted.

CO_2 concentration, comparative evaluation of C_3 and C_4 plants

Increase in CO_2 concentration may be able to increase the photosynthesis rate of the plants. This could be due to lower rate of photorespiration that can be further enhanced with the increase in temperatures. This results in higher rate of photosynthesis in C_3 plants rather in C_4 and crassulacean acid metabolism (CAM) plants (Sage and Monson, 1999). It has been reported that when CO_2 concentration were doubled the growth in C_4 plants were spurred by 10-20 %, however, in C_3 plants this amounts to 30-45 % (Ghannoum et al., 2000). Numerous studies have been showed on increasing CO_2 concentration in C_3 plants that showed photosynthesis of C_3 plants may function even at very low CO_2 levels leading to remarkable increase in several aspects like growth, yield and carbon assimilation (Bernacchi et al., 2003; Long et al., 2004). However, in C_4 plants under low CO_2 levels, the process of carbon assimilation is saturated due to the utilisation of HCO^{3-} rather than CO_2. This implies that when plants (C_3 or C_4 plants) are exposed to high CO_2 levels then carbon assimilation is effected to some extent. Reddy et al. (2010) had shown the response of high CO_2 concentration on 45 plants (of which 40 were of C_3; 2 of C_4 and 3 of CAM) and found that a photosynthetic acclimation

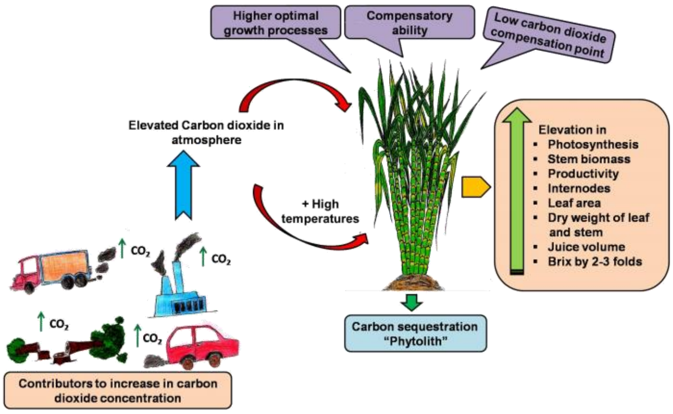

Fig 1. Effect of elevated carbon dioxide concentration on sugarcane crop. Sugarcane has been bestowed with four natural endowments, *viz*, higher optimal temperature for growth processes, compensatory ability, low carbon dioxide compensation point and carbon sequestration ability in respect to increasing CO_2 concentration that helps in showing better performance under high CO_2 concentrations in comparison to other crops.

was significantly positive under high CO_2 in C_3 plants and CAM plants, however, in C_4 plants (Sorghum and Panicum) it was not so. One of the reasons behind could be the less number of C_4 plants studied. C_4 plants show positive reaction under such condition as well as when temperature increases. They also show same reaction under arid condition (Ghannoum et al., 2000; Sage and Kubien, 2003). Under high CO_2 concentration C_4 plants had relatively more photosynthetic nitrogen use efficiency as high CO_2 exasperate nitrogen limitations (Sage and Kubien, 2003). Reddy et al. (2010) had revealed that under high CO_2 levels the rate of respiration is affected in C_3 plants while not much known in C_4 plants.

C_4 plants react to high CO_2 concentration in different manner due to which it becomes hard to understand the mechanism used by the plants belonging to this group for such condition (De Souza et al., 2008). C_4 plants possess a unique CO_2 device that helps them in attaining higher photosynthetic capacity as compared to C_3 plants under elevated CO_2 concentration (Matsuoka et al., 2001). Earlier studies had showed that plants of this group have the ability to enhance their rate of photosynthesis and biomass by 25 % and 33 %, correspondingly (Wand et al., 1999) as seen in sugarcane. But sorghum and maize were the two plants of this group which showed a contrastingly response to increased CO_2 concentration. They respond to increased CO_2 concentration only if there is drought condition also (Ottman et al., 2001; Leakey et al., 2006). The presence of nutrients in the soil also effects the growth of C_4 plant under such conditions (Cousins and Bloom, 2003; Tang et al., 2006). Contrastingly, Drake et al. (1997) had revealed that in C_4 species, a decrease of nearly 20 % in stomatal conductance was seen. However, due to their anatomical and physiological characters, they are assumed that they have higher potential of closing their stomata under high CO_2 concentration as compared to C_3 plants (Tolbert and Zelitch, 1983).

Role of sugarcane in managing CO_2 concentration in the atmosphere

Being a C_4 plant, sugarcane has a very low CO_2 compensation point, ranging between 0-10 ppm. This implies that they can deplete all the atmospheric CO_2 at a given temperature in a closed ambient atmosphere. However, this is not in case of other crops like, wheat, soybean, *etc*., which have high CO_2 compensation point (40-100 ppm) (Black, 1971). Due to a C_4 plant, the stomata get partially closed and so does the leaf transpiration process under high CO_2 levels in sugarcane plants. This leads to lower sap flow thereby increasing the potential of xylem that ultimately causes improvement in water status of the plant (Owensby et al., 1997). Due to this, increase in sugarcane stalk fresh mass has been reported (Marin et al., 2012).

Another natural endowment bestowed upon sugarcane for managing CO_2 concentration in the atmosphere is the carbon sequestration. This refers to a long-term storage of CO_2 (or other forms of carbon) in plants and soil. This is a natural mode for counteracting CO_2 productions and subsequent global warming to mitigate the effects. Similar to several other grasses, sugarcane also possesses such an exclusive sequestration procedure for making *plantstone* or *phytoliths*. By this process around 300 Mt of CO_2/year from the atmosphere is extracted and gets stored in the soil for a thousands of years (Par and Sullivan, 2007, Par et al., 2009). This phenomenon is also called phyto-occluded carbon (PhytOC). Par and Sullivan (2005) have projected the PhytOC yield of a sugarcane crop to remain 18.1 g C m^{-2} yr^{-1}, which is sustainable over millions of years and at the same time comparable with carbon sequestered while converting a cultivated land to forest or grassland or changing the conventional tillage to no-tillage. This amounts to 181 kg C sequestered/ha year.

Besides these, there are several other natural endowments bestowed upon sugarcane like compensatory capacity, higher optimal temperature for maximum of its growth processes (excluding for sucrose accumulation) which adds in mitigating the effects of climate change and imparts partial resilience to sugarcane crop.

Conclusion

Sugarcane crop is the main raw material for production of sugar and alcohol throughout the world. Climate change leads to escalation in concentration of GHGs in the troposphere, especially the emission of CO_2, temperatures, occurrence of extreme events, drought and floods, increasing level of the sea. The key reasons for climate change are the elevated CO_2 concentration. In CO_2 increasing scenario, on comparing C_4 plants with C_3 plants in this respect had showed that in C_3 plants at very low CO_2 concentration, photosynthesis function properly but in C_4 plants utilization of HCO^{3-} rather than CO_2 leads to saturation of carbon assimilation. Furthermore, in sugarcane crop with elevated CO_2 concentration, morphological changes have been seen. There is an escalation in photosynthesis, water use efficiency, biomass production and lower levels of acid invertase under high CO_2 concentration. Besides, elevation in CO_2 concentration affects yield of several crops; however, sugarcane is the crop which has been bestowed with two important abilities, *viz*., low compensation point (ranging between 0-10 ppm) and *carbon sequestering ability* (181 kg C is sequestered/ha year) that helps in managing the effect of higher concentration of CO_2 on the crop. Moreover, sugarcane cultivation in the increasing scenario of CO_2 will also be beneficial for the higher productivity and yield of other crops as it will be able to lower the concentration of CO_2 to some extent.

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