

Impact of Climate Change Drivers on C4 Plants: A Review

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ABSTRACT

The productivity of plant community is affected by climate change drivers in three pathways including direct effects of drivers on plants, the community response of species abundances to drivers and the feedback effect of community change on productivity. The productivity of C4 plants is significantly influenced by C4 metabolic process of plants. Apart from these metabolic pathways, one of the most essential elements that influence the yield of C4 plants are seasonality and temperature. In addition to all, these climatic climate change drivers have a great influence on the productivity of C4 plants. The present review focuses on how C4 plants mitigate climate change.

Keywords: *Crassulacean Acid Metabolism, C4 Photosynthesis, C3 Photosynthesis, Photorespiration.*

INTRODUCTION

The two basic photosynthetic pathways are C3 and C4 photosynthesis that are adding the worldwide essential profitability along with Crassulacean Acid Metabolism (CAM) which is a third pathway found in succulents (Still et al., 2003). The main carbon source for these three pathways is atmospheric CO₂. The C4 and CAM photosynthetic plant have a specific component that make high fixations of CO₂ at the site of photosynthetic carboxylation. The advanced land plants i.e. Angiosperms do the

process of C4 photosynthesis. The process of C4 photosynthesis is not found in older groups including Gymnosperms i.e. coniferous trees and Pteridophyta i.e. ferns (Sage & Monson, 1998). The Angiosperms, that are approximately 6000 out of the approximately 10,000 Monocotyledonae, have C4 photosynthesis. It is also demonstrated that only 1500 of the approximately 300,000 Dicotyledonae have the process of C4 photosynthesis (Sage & Monson, 1998).

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Among subtropical and tropical taxa, the C4 taxa are more common. They are not present in arctic and temperate taxa (Sage & Monson, 1998). Furthermore, the C4 taxa are typically active during the summer within both annual/perennial monocots and dicot annuals. The C4 taxa are not common within the shrub life. The process of C4 photosynthesis largely occur in Halophytic plants that occurring on saline soils. Halophyte belongs to the family Chenopodiaceae which are mostly dicots. Mostly, the C4 photosynthesis process doesn't found in trees. In case of herbaceous vegetation, C4 photosynthesis is also most common and the herbaceous vegetation include the both annuals as well as perennials. In case of modern agriculture, fertilizers are very important part (Adnan et al., 2020) however, the use of microbes as natural fertilizer is becoming the most trending field in era of today (Rehman et al., 2020a). The unhealthy impacts of chemical fertilizers are making them unusable in agriculture (Rehman et al., 2020b). According to the estimation of Rehman et al. (2020a), about 28.8 million tons of nutrients will be required for the production of 321 million tons of production of grains of food. But still, 21.6 million tons of nutrients are available. There is a gap of about 7.2 million tons between the nutrient supply and nutrient removal (Rehman et al., 2020a).

The increase in the primary production is necessary to secure and feed the energy requirements of increasing and expanding human population (Rehman et al., 2020b). Genetical modification are required to be done to increase the productivity of plants. It is noted that many plant species have evolved under the selection pressure due to a low productivity. Many species are subjected to selection pressure in natural or semi natural ecosystem including as resource limitation and frequent disturbances (Scheiter et al., 2012). These selection pressures mostly favor those plants which use moderate resources, that are short-statured or those which have relatively large amount of carbon (C) in root system which result in the maximum aboveground growth rate. Grassland plants are increasingly

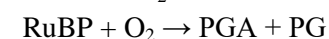
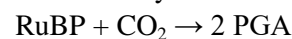
subject to environmental and physiological modifications associated with climatic change drivers (Toor et al., 2020). The aboveground net primary productivity (ANPP) is influenced by climate change drivers. Like other ecosystem processes, it also includes at least three components:

- (i) The direct or physiological responses of plants to drivers also known as direct ecosystem responses (Smith et al., 2009)
- (ii) The impact of climate drivers on the composition of plant community
- (iii) The feedback effects of community change on ecosystem processes (Suding et al., 2008).

In order to categorizing species into groups that respond similarly to climate change drivers, a considerable effort has been devoted. However, for the prediction of physiological responses to drivers the species grouping is very useful. Furthermore, species groupings are also useful for predicting community responses to drivers but it may not predict feedback effects of community change on ANPP and other processes.

A Mechanistic rationale for the benefit of C4 Photosynthesis in a Low-CO₂ World

The enzyme Rubisco primarily know as ribulose bisphosphate carboxylase-oxygenase catalyze the initial photosynthetic fixation of CO₂ in C3 plants. The Rubisco enzyme has both carboxylase and oxygenase activities:



Here the RuBP is ribulose bisphosphate, PGA is phosphoglycerate and PG is phosphoglycolate. The oxidative metabolism of phosphoglycolate results in the process of photorespiration which cause the CO₂ loss. The process of photorespiration increases with elevated temperature because Rubisco oxygenase activity is temperature sensitive and increase with increase in temperature. Whereas, the carboxylase activity is temperature insensitive. Biochemically, a CO₂ concentrating mechanism that attain the high CO₂ levels at the site of Rubisco activity is represented by photorespiration process. In C4 plants. The PEP carboxylase fixes CO₂ more

rapidly by than Rubisco. It results in relatively high level of CO_2/O_2 inside bundle sheath cells, thereby eliminating the photorespiration process. The lack of photorespiratory activity at the whole-leaf level is the common advantage of C4 photosynthesis. At low level of light intensity, this is expressed as an enhanced photosynthetic quantum yield. At high light levels, the significant reduction in photosynthesis in C3 plants is resulted by photorespiration in today's atmosphere. The increases in quantum yield result in the increase in CO_2 which is decreased by elevations in temperature. On the other hand, because of no photosynthesis occurrence on the leaf level, the C4 plants remain constant with temperature. It is predicted by the quantum yield model that C4 photosynthesis are expected to expand significantly under low availability of CO_2 , such as occurred during glacial periods.

Factors affecting the C4 monocot distribution

It is predicted by the model given by Ehleringer et al. (1998). that C4 taxa are likely to occur in those habitats having a warmer growing season at any given atmospheric CO_2 level. It is demonstrated by this model that the growing-season temperatures are different from non-growing-season temperatures. when the plants experiencing a cold, winter-precipitation system and then followed by the hot, dry summer is not considered as warm-temperature ecosystems. Teeri and Stowe (1976) were the first to show that C4 grass distributions across the Great Plains of North America were linearly related to growing season temperature. The quantum yield model predicts that at some time in Earth's recent history the atmospheric CO_2 declined to a point where a threshold was crossed and C4 plants would be favored globally in the warmest growing-season habitats. Cerling et al. (1997) provided convincing evidence for a global expansion of C4- dominated ecosystems appeared in warmer, lower latitudes and not in higher, cooler latitudes approximately 6 to 8 million years). Oxygen isotope ratio data suggest that increased

monsoonal activity in southern Asia and the Indian subcontinent preceded the expansion of C4 ecosystems by 1 to 2 million years.

Was Atmospheric CO_2 being responsible for C4 extension During Glacial Periods?

The diversity of CO_2 extent in atmosphere between the range of 180 and 280 ppm during the last 420,000 years (Petit et al., 1999) should have influenced on the amount of C3/C4 taxa. The ecosystems having cultivating season with scalding temperature the latent ampleness of C3 and C4 taxa waver as CO_2 rise and reduced between the glacial and interglacial period is the prognosis of quantum yield model. There is now enough confirmation from ecosystems in North America, South America, Central America, and Africa explaining that C3 taxa is superceded by c4 taxa during glacial periods and that C4 taxa often reduced in ampleness following the last glacial maximum (Huang et al., 2001). Within recent past, Harrison and Prentice (2003) have scrutinized the limit to which the variation in global vegetation between the past glacial maximum and recent have been constrained by variation in climate i.e. in temperature and precipitation or variation in both climate and atmospheric CO_2 . To comparision with the recent-day aerial limit of utmost biomes, this model propheces that with the variation in climate alone there would be minor variation in global extent of forest. However, with variation in atmospheric CO_2 , there were huge decline in the extent of tropical forest.

Influence of seasonality on the growth of plants

Seasonality is a salient eco-friendly phenomenon that is frequently strenuous to with draw from paleo-inspections. It is indispensable to concede that variation in circulating pattern of oceans could lead to variation in the seasonality of condensation. For instance, the midden data of pack rat stipulate that the degree of summer rains in the western United States resorted southward during the last several thousand years (Betancourt et al., 1990). Moreover, water shortage is most important problem worldwide

negatively influenced by climate change (Adnan, 2020a & Adnan, 2020b). According to prognosis of quantum yield model, the condemnatory element during cultivating season would be temperature and water. In the trueness of which (summer) the vegetation would probably be C3 because the temperature is not warm in late winter and spring cultivating season. To demonstrate the reason of favouring one photosynthetic pathway than other, suppose the extent of C3/C4 monocots in southern California and Florida today. It is clarified that both the places are at same latitudes, the amount of C4 is maximum in Florida and minimum in southern California (Sage & Monson, 1998). The reason is that the condensation is maximum in California when the cool spring season comes due to huge abundance of C4 plant. Whereas the predominant condensation in Florida is in the warm summer season. This demonstrates the seasonality of the condensational event that results in rising of C4 abundance because of variation in temperature between winter and summer in temperate regions.

Factors limiting the sufficiency of C4 monocot species

The abundances of C4 taxa is swayed by the elements of both weather and non weather pattern. The atmospheric CO₂ and O₂ levels, temperature, and seasonality of condensation are considered as elements of weather pattern. Man is involved in promoting such as deforestation by taking part in element of non weather pattern. For instance, forest demolition connected with the expansion of the Mayan civilization in Central America (Huang et al., 2001) and expansions in Ethiopia (Eshetu & Hogberg, 2000) has huge impact by variation in carbon isotope ratios of soil organic matter and lake sediments, allowing a time course reformation of the C3/C4 shifts. Basically, increasing fluctuations will make ecosystems appear more C4 like, since C3 trees are more probably to be influenced by fluctuations such as fire.

Affect of temperature and CO₂ partial pressure on photosynthesis:

Photosynthesis is maximum in C4 at rising temperature and minimum CO₂ due to

dependence of photorespiration on temperature and CO₂ abundance (Brooks & Farquhar, 1985). C4 plants attained this through a biochemical CO₂-pump that in which an enzyme with high affection for CO₂ known as Phospho-enolpyruvate carboxylase (PEPCase) and by centralizing Rubisco in bundle-sheath cells (Hatch, 1987). Pumping CO₂ is not cheap. Each pumped molecule of CO₂ needs 2 ATP, formed as a result of photophosphorylation at a rate of ~8 photons per ATP (Furbank et al., 1990). That is the reason of increasing maximum quantum yield in C4 instead of in C3 plants at maximum temperature or minimum intercellular CO₂ and vice versa. The familiar relation is also found between photosynthetic mode and temperature at rising irradiances. This is due to rising of light-saturated photosynthetic rate at higher temperature in C4 plants.

CONCLUSION

The majority of plants which have C3 versus C4 photosynthesis are brawny match to two environmental elements including atmospheric CO₂ and growing-season temperature. The mechanistic quantum yield prognosis the union of CO₂ and temperature that influenced the variation in photorespiration that favor C4 taxa. C4 taxa is also favoured by low atmospheric CO₂ levels and warm temperature. The abundance of C4 dominated ecosystems is of only recent origin, with C4 dominated ecosystems having expanded globally about 6 to 8 million years ago. The seasonality and disturbance demonion are significant ecological considerations that can contribute to the C3/C4 dominance in transition climate regimes under a constant atmospheric CO₂. Future increases in atmospheric CO₂ are probably to favor the expansion of C3 dominated ecosystems over C4 dominated ecosystems. The fluctuations in climatic factors have great influenced on C4 plants than on the C3 plants which are influenced by the fluctuations such as fire. Also, high temperature, low CO₂ these are the factors that favour the increasing rate of photosynthesis in C4 plant and opposite effect occurs in C3 plants.

REFERENCES

- Adnan, M., Asif, M., Bilal, H. M., Rehman, B., Adnan, M., Ahmad, T., Rehman, H. A., & Anjum, M. Z. (2020). Organic and inorganic fertilizer; integral part for crop production. *EC Agri.* 6(3), 01-07.
- Adnan M. (2020). Remote Sensing an Innovative Way to Improve Crop Production: A Review. *Current Trends Engin Sci (CTES)*. 1(1), 1003.
- Adnan M. (2020). Application of Selenium; A Useful Way to Mitigate Drought Stress; A Review. *Open Access J. Biog. Sci. Res.* 3(1), 1-4. DOI: 10.46718/IBGSR.2020.01.000064.
- Betancourt, J. L., Van Devender, T. R., & Martin, P. S. (1990). *Packrat middens: the last 40,000 years of biotic change*. University of Arizona Press.
- Cerling, T. E., Harris, J. M., MacFadden, B. J., Leakey, M. G., Quade, J., Eisenmann, V., & Ehleringer, J. R. (1997). Global vegetation change through the Miocene/Pliocene boundary. *Nature*, 389(6647), 153-158.
- Eshetu, Z., & Högborg, P. (2000). Reconstruction of forest site history in Ethiopian highlands based on ¹³C natural abundance of soils. *AMBIO: J. Human Environ.* 29(2), 83-89.
- Furbank, R. T., Jenkins, C. L. D, Hatch, M. D. (1990). C₄ photosynthesis: quantum requirement, C₄ and overcycling and Q-cycle involvement. *Funct. Plant Biol.* 17(1), 1-7.
- Harrison, S. P., & Prentice, C. I. (2003). Climate and CO₂ controls on global vegetation distribution at the last glacial maximum: analysis based on palaeovegetation data, biome modelling and palaeoclimate simulations. *Glob. Chang. Biol.* 9(7), 983-1004.
- Hatch, M. D. (1987). C₄ photosynthesis: a unique blend of modified biochemistry, anatomy and ultrastructure. *Biochimica et Biophysica Acta (BBA)-Reviews on Bioenergetics*, 895(2), 81-106.
- Huang, C., Yang, L., Wylie, B. K., & Homer, C. (2001). A strategy for estimating tree canopy density using Landsat 7 ETM+ and high resolution images over large areas.
- Petit, J. R., Jouzel, J., Raynaud, D., Barkov, N. I., Barnola, J. M., Basile, I., & Delmotte, M. (1999). Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature*, 399(6735), 429.
- Rehman, F. U., Kalsoom, M., Shafique, T., Junaid, S., Khalid, N., Adnan, M., & Ali, H. (2020a). Biological Importance of Microbes in Agriculture, Food and Pharmaceutical Industry: A review. *Innovare J. Life Sci.* 8(6), 1-4.
- Rehman, F. U., Kalsoom, M., Nasir, T. A., Adnan, M., Anwar, S., & Zahra, A. (2020b). Chemistry of Plant–Microbe Interactions in Rhizosphere and Rhizoplane. *Indian J. Pure Appl. Biosci.* 8(5), 11-19. DOI: <http://dx.doi.org/10.18782/2582-2845.8350>.
- Sage, R. F., & Monson, R. K. (1998). *C₄ plant biology*. Elsevier.
- Scheiter, S, Higgins, S. I., Osborne, C. P., Bradshaw, C., Lunt, D., Ripley, B. S., Taylor L. L., & Beerling D. J. (2012). Fire and fire-adapted vegetation promoted C₄ expansion in the late Miocene. *New Phyto.* 195, 653–666.
- Smith, M. D., Knapp, A. K., & Collins, S. L. (2009). A framework for assessing ecosystem dynamics in response to chronic resource alterations induced by global change. *Ecol.* 90, 3279–3289.
- Still, C. J., Berry, J. A., Collatz, G. J., & DeFries, R. S. (2003). Global distribution of C₃ and C₄ vegetation: carbon cycle implications. *Geophys. Res. Lett.* 17(1), 6-1.
- Suding K. N., Lavorel, S., Chapin, F. S., Cornelissen, J. H. C., Diaz, S.,

- Garnier, E., Goldberg, D., Hooper, D. U., Jackson, S. T., & Navas, M. L. (2008). Scaling environmental change through the community-level: a trait-based response-and-effect framework for plants. *Glob. Chang. Biol.* 14, 1125–1140.
- Toor, M. D., Rehman, F., Adnan, M., Kalsoom, M., & Shahzadi, L. (2020) Relationship between Environment and Agriculture: A Review. *SunText Review Biot.* 1(2), 1-5.
- Teeri, J. A., & Stowe, L. G. (1976). Climatic patterns and the distribution of C 4 grasses in North America. *Oecologia*, 23(1), 1-12.