Agriways 9 (1) : 26-32, June 2021
DOI:

ISSN: 2321-8614 (Print)
ISSN: 2454-2318 (Online)

Research Article

Effect of Elevated CO_2 on Dry Mater Partitioning in Brassica Species Under Moisture Stress Condition

Ranjan Das

Dept. of Crop Physiology, Assam Apicultural University. Jorhat-785013
Email: rdassan1966@gmail.com

Received: 05 June 2021/Accepted: 24 June 2021

Abstract Climate change has brought about drastic changes in agro-climatic conditions in recent years resulting in multiple environmental stresses. The increase in temperatures due to rising atmospheric CO_2 usually combines with moisture stress conditions and under rising atmospheric CO_2, the availability of nutrients may ultimately limit the capacity of plants to assimilate carbon. Elevated CO_2 enhances WUE, fresh mass, dry mass, leaf area and leaf thickness and the dry matter partitioning to leaves determines biomass responsiveness to elevated atmospheric CO_2. This increase in dry matter under elevated CO_2 is probably due to greater leaf growth, which in turn provides greater photosynthetic surface area and leaf net photosynthetic rate and thereby increasing dry matter production.

Keywords: Biomass, Elevated CO_2, Moisture stress, Brassica, and Dry mater partitioning,

Introduction

Ongoing and future predicted global climate changes have been mostly associated with increases in both atmospheric CO_2 and air temperature, in addition to alterations in precipitation patterns (Avilaa et. al 2020). In terms of geological or evolutionary scales, these changes have occurred rapidly from the industrial revolution period onwards (IPCC, 2014), and are already impairing both natural and agricultural ecosystems. Therefore, plants are expected to face abiotic stresses, such as supra-optimal temperatures and limited water availability, to a greater extent than in the ambient where they naturally evolved. Nonetheless, elevated CO_2 is believed to potentially mitigate these stressful factors (Abd Elgawad et al., 2016; Rodrigues et al., 2016).

In general, increased CO_2 has a positive effect on crop growth, especially for C_3 crops, which is called a "fertilizer effect" (Ainsworth and Long, 2004). However, CO_2 has the highest positive "radiative forcing" (RF) of all the human-influenced climate drivers (IPCC, 2013). Air temperature (Tair) also increases with an increase in atmospheric CO_2 and may increase by 2°C, based on simulations of general circulation models (GCMs) under the newly developed representative concentration pathway (RCP) 4.5 and 6.0 climate scenarios. The effects of increased Tair on crop growth mostly vary with background environmental conditions, such as temperate or biome (He et al., 2017; Liu et al., 2014; Xu et al., 2018; Zhang et al., 2015). Numerous studies have focused on the independent effects of these two climate change factors on crop growth (Ainsworth and Long, 2004; Pang et al., 2006; Peng et al. 2004), but less research has been conducted to evaluate the integrated effects of CO_2 and temperature. Segura et al., (2001) studied the effects of CO_2 enrichment on the bio-productivity and nutrition of a cucumber (cv. Marumba) under greenhouse conditions and they found that the treatment with CO_2 increased total accumulated dry matter by 14.4 and 13.3 per cent in the first and second crop cycles, respectively. The nutrient content in aerial organs, expressed in percent of dry matter, was also affected by CO_2 enrichment. The crop grown in a CO_2-enriched atmosphere consumed a greater amount of nutrients, mainly N, K, Ca and Mg. Liu et al. (2002) also reported that elevated CO_2 resulted in larger fresh and dry mass and higher root-to-shoot ratio in two-year-old needles in young trees of Sitka spruce (Picea sitchensis). Suter et al. (2002) reported that grass swards showed a higher root-shoot ratio of dry matter (R: SDM) at elevated CO_2 than at ambient CO_2. Elevated CO_2 in the field increased root dry matter (109%), R: SDM (44%) and, in accordance, root-shoot 14C ratios (R: S14C, 39%). The elevated levels of CO_2 increased the carbon sequestering in the ecosystem and simulated plant growth leading to dry matter accumulation, which may change, based on nutrient availability. It is believed that in an environment of rising atmospheric CO_2, the availability of nutrients may ultimately limit the capacity of plants to assimilate carbon (Riviere-Rolland et al., 1996). In an experiment with soybean plants on CO_2 enrichment Bunce (1995a) noted decline in respiration rate. He also observed that response of respiration rate to CO_2 was not affected by the form of N. He showed that high CO_2 (700 cm3m-3) applied only during night conserved C and increased dry matter of soybean during initial growth compared with the constant 350 cm3m-3 CO_2 treatment. Long-term net assimilation was increased by high CO_2 in the dark without any increase in day by the high CO_2 in the dark to values equal to those of plants continually exposed to higher CO_2 concentration (Bunce 1995b). Thus, photosynthesis rate also depended on other processes, principally photorespiration and change in respiration even to cause large variations in dry matter production (Amthor, 1989 and Amthor, 1994). Here we hypothesize that elevated CO_2 could positively affect Brassica spp. performance under moisture stress conditions. Therefore, in the present study, we aimed to test how dry matter partitioning is affected by elevated CO_2 and drought, and how this could impact shifts in biomass accumulation. For this purpose, we designed an experiment using FACE technology. The information are generated on the distribution of DM in response to the combination of CO_2 and moisture will improve our understanding of the regulation of intra-plant partitioning of photosynthetic assimilates.

Methodology

Plant Material

Brassica cultivars viz. Brassica juncea cv. RH-30 and Brassica campestris cv. Pusa gold was collected and grown for the present investigation.

Experimental Site and Growth Conditions

The response of both the species to elevated CO_2 was studied using Free Air CO_2 Enrichment Technology (FACE) to simulate the doubling CO_2 concentration at, IARI, New Delhi-12. The crops were grown in the field and inside the Mid Free Air CO_2 enrichment (FACE) facility in 8 m diameter circles. An elevated CO_2 concentration of 550 µmolmol-1 was maintained throughout the crop growth period with the help of computer-based PID valves. There was no exogenous supply of CO_2 to the normal air under ambient field condition. Field was prepared by recommended agronomic practices.

Cultural Practice

Farmyard manure was applied at the rate of 5 tons per hectare at the time of field preparation. The plant spacing, fertilizer application at the rate of 30+30:60:40 kg per hectare of nitrogen, phosphorus and potassium and other cultural practices were followed as reported by Uprety et al. 2001.

Moisture Stress Treatment

Moisture stress treatment was given by restricting irrigation and bringing the soil moisture level between 7 and 10% compared to 22-25% under irrigated condition. All the observations were taken in triplicate for each treatment at Stage-1: vegetative (25 days after sowing), Stage-2: flower bud initiation (45 DAS), Stage- 3: 50% flowering (60 DAS) and Stage-4: post flowering (75DAS).

Plant Biomass Estimation

Plants were separated into root, stem, leaves and siliquae at different stages of growth. Samples were dried in an oven at 80oC till constant weight. Dry weight of components of plant parts was measured subsequently and growth analysis was done (Gardener et al., 1985.) The dry matter partitioning to different parts of the plant i.e. leaf, stem, root, shoot, and pods was studied according to the method of Thurling (1974).

Results

Dry Matter Distribution

Leaf Dry Weight

Elevated CO_2 brought about a significant increase in leaf dry mass ranging from 30% (155 DAS) to 75% (95 DAS) [Fig.1 (a-d) & 2 (a-d)]. The dry weight of leaves was significantly higher in 'RH-30' in comparison to 'Pusa gold' throughout the growth period. Moisture stress markedly reduced the leaf dry weight ranging from 51% (35 DAS) to 84% (95 DAS). The stress induced reduction in ambient and elevated conditions varied from 40% (35 DAS) to 60% (95 DAS) and from 26% (150 DAS) to 39% (95 DAS) respectively in 'Pusa Gold', and from 30% (150 DAS) to 59% (115 DAS) and from 25% (150 DAS) to 35% (115 DAS) in 'RH-30' respectively.

Stem Dry Weight

There was significant increase in stem dry weight under elevated CO_2 condition ranging from 18% (55 DAS) to 43% (155 DAS) [Fig.1 (a-d) & 2 (a-d)]. A significantly higher amount of stem dry mass was recorded in 'RH-30'. Moisture stress significantly reduced it ranging from 28% (55 DAS) to 53% (115 DAS). The stress induced reduction in stem dry mass under ambient and elevated CO_2 conditions varied from 30% (55 DAS) to 45% (155 DAS) and from 17% (75 DAS) to 29% (35 DAS) respectively in 'Pusa Gold'. The reduction in 'RH-30' varied from 27% (75 DAS) to 43% (150 DAS) and from 16% (75DAS) to 27% (95 DAS) under ambient and elevated CO2 conditions respectively.

Root Dry Weight

Elevated CO2 brought about significant increase in dry weight of roots ranging from 23% (155 DAS) to 36% (75DAS, 95DAS and 115DAS) [Fig.1 (a-d) & 2 (a-d)]. Root dry weight was greater in 'RH-30'. Moisture stress significantly reduced the root dry weight ranging from 22% (55 DAS) to 40% (35 DAS and 115 DAS). The stress induced reduction in root dry weight under ambient and elevated conditions varied from 28% (55DAS) to 48% (35 DAS) and 16% (115 DAS) to 23% (150 DAS) respectively in 'Pusa Gold'. The reduction in 'RH-30' varied from 24% (75 DAS) to 28% (35 DAS) and from 16% (115 DAS) to 19% (35 DAS), respectively.

Pod Dry Weight

The higher CO2 concentration brought about marked increase in pod dry weight ranging from 40% (75DAS) to 37% (55DAS) [Fig.1 (a-d) & 2 (a-d)]. It was greater in 'RH-30' throughout the growth period. Moisture stress caused significant reduction in pod dry weight ranging from 48% (75 DAS) to 57% (55 DAS). The stress induced reduction in pod dry weight under ambient and elevated CO_2 conditions varied from 43% (155 DAS) to 48% (115 DAS) and 18% (115 DAS) to 30% (155 DAS) respectively in 'Pusa Gold', whereas, the reduction in 'RH-30' varied from 38% (75 DAS) to 42% (95 DAS) and from 17% (115 DAS) to 28% (95 DAS), respectively.

Total Plant Dry Weight

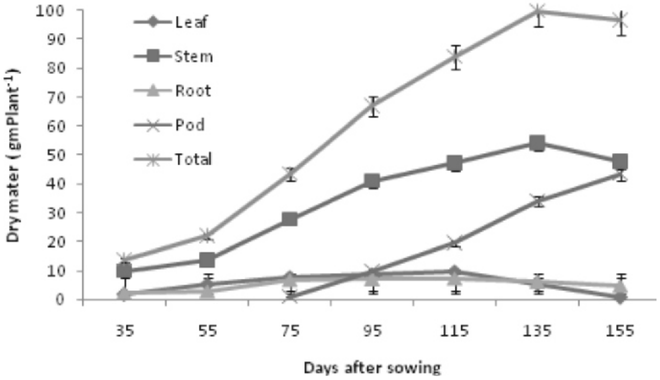
The total dry weight of plant was significantly increased under elevated level of CO_2 condition ranging from 10% (35 DAS) to 44% (95DAS) [Fig.1 (a-d) & 2 (a-d)]. It was higher in 'RH-30' cultivar. It was significantly lower under moisture stress condition throughout the growth period ranging from 19% (35DAS) to 56% (115 DAS). The stress induced reduction in total plant dry weight under ambient and elevated condition varied from 18% (35 DAS) to 47% (95 DAS and 115 DAS) and 15% (35 DAS) and 32% (135 DAS) in 'Pusa Gold' respectively and from 14% (35 DAS) to 41% (115DAS) and from 12% (115 DAS) to 26% (35 DAS) in 'RH-30', respectively.

Discussion

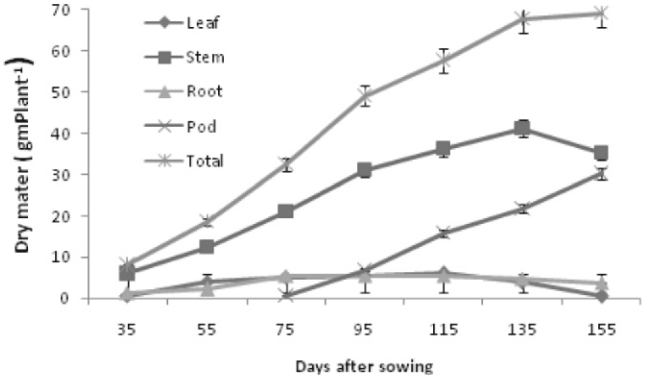
The dry matter partitioning in different parts such as leaf, stem, root and pod were significantly enhanced by CO_2 enrichment. Results indicated that CO_2 has a greater effect on dry matter partitioning. Highest dry matter partitioning was recorded under elevated CO_2 in both the cultivar. But a significant genotypic variation was recorded in both the cultivar. Highest partitioning of dry mater matter was recorded in Brassica juncea cv. RH-30 compared to Brassica. Campestris cv. Pusa gold in every part of the plant under each stage of growth. This finding is in accordance with the findings of some other workers also. Liu et al. (2002) reported that the elevated CO_2 resulted in larger fresh mass, dry mass, leaf area and leaf thickness in two-year old needles of Sitka spruce (Picea sitchensis). Tree height, basal diameter and biomass production were also increased, regardless of N supply. The dry matter partitioning to leaves determines biomass responsiveness to elevated atmospheric CO_2 in comparison between African and Asian rice genotypes (Masuya et. al. 2020). Similarly Wullschleger and Norby (2001) demonstrated that 28 per cent increase in WUE was attributed to 15 per cent increase in dry matter increment and 12 per cent decrease in water use under elevated CO_2 .According to them higher soil water content in elevated CO_2 made itself available to either postpone the onset or reduce the severity of drought and accordingly this conserved water alone attributed to 20 per cent increase in above biomass extending the photosynthetic active period under moisture stress condition. CO_2 has a greater effect on dry matter partitioning. Wang et al.,2015 reported that that elevated CO_2 promoted rice grain yield by enhancing the leaf net photosynthetic rate and increasing dry matter (DM) accumulation in rice. The main reason for the increases in yield with elevated CO_2 were was clearly due to increased dry matter production, rather than any changes in partitioning to the grain. Vigna radiata L. also showed an increase in total biomass under elevated CO_2 conditions (Srivastava et al. 2001); An increase in the total dry matter (DM) of rice plants under elevated CO_2 (12 to 40 %) has also been reported (Kim et al., 2001; De Costa et al., 2006). The increase in dry matter and growth of root , stem and leaves proved that CO_2 enrichment on the atmosphere can stimulate the photosynthesis rate which ultimately leads to an increase in dry matter and growth. (Srivastava et al 2001) in Mungbean. Increased photosynthesis due to elevated CO_2 was also observed by Das 2020 in Brassica spp. The increase in stem and leaf growth with elevated CO_2 caused an overall increase in total biomass in black gram under irrigated and moisture stress conditions (Vanaja et al 2006).

Conclusion

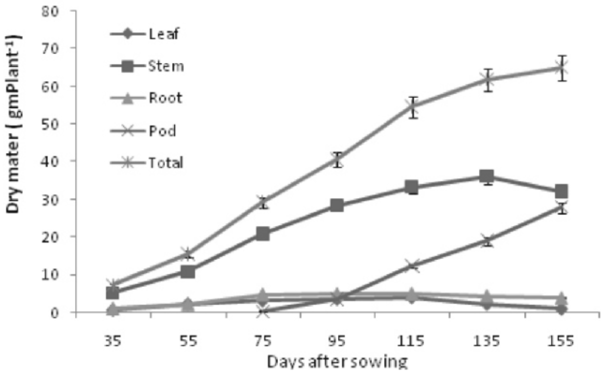
The increase in the dry matter of root, shoot and leaf proved that CO_2 enrichment of the atmosphere will be beneficial for the crops for better establishment and greater productivity may be due to resulted from greater leaf growth, which in turn produced greater photosynthetic surface area at the early stages of plant. Higher biomass in root indicated the plants ability to facilitate better initial establishment and growth under moisture stress environment. This deeper rooting would be an advantage if climates became drier.



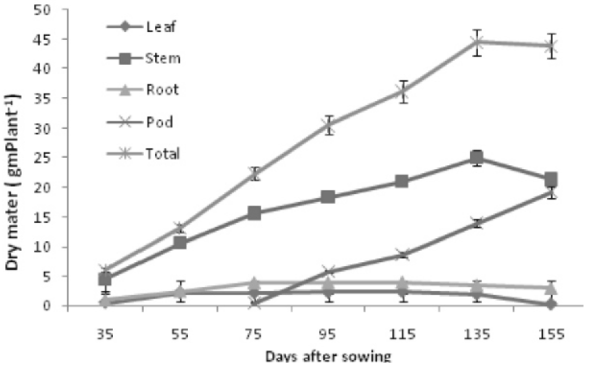
Dry mater partitioning of various parts of Pusa Gold under FACE and irrigated condition



Dry mater partitioning of various parts of Pusa Gold under FACE and drought condition

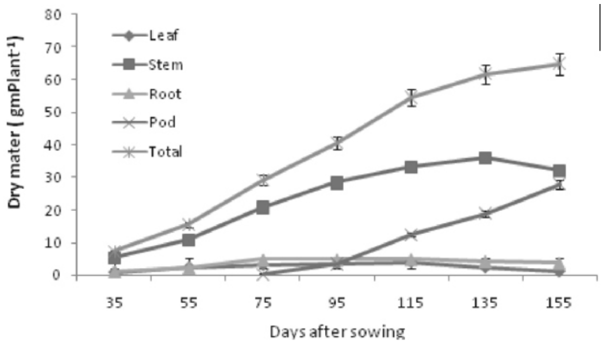


Dry mater partitioning of various parts of Pusa Gold under AMB and irrigated condition

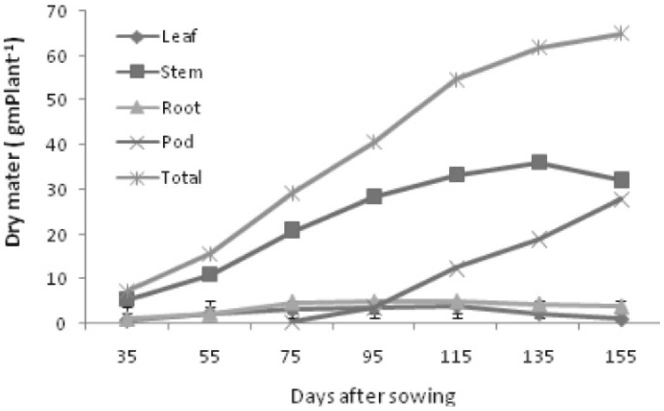


Dry mater partitioning of various parts of Pusa Gold under AMB and drought condition

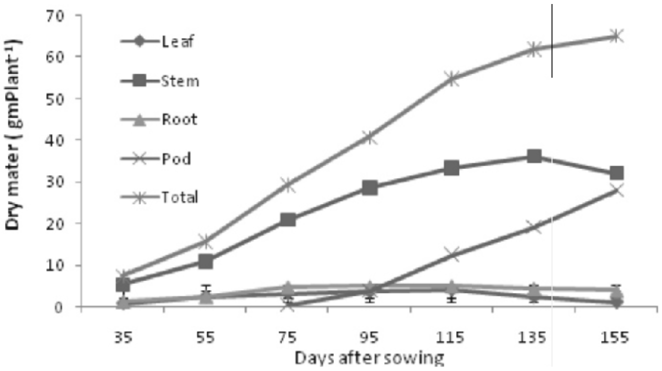
Fig. 1. Interactive effect of elevated CO2 and moisture stress on dry matter distribution o leaves, stem, root, pod and total dry weight of cv. Pusa gold



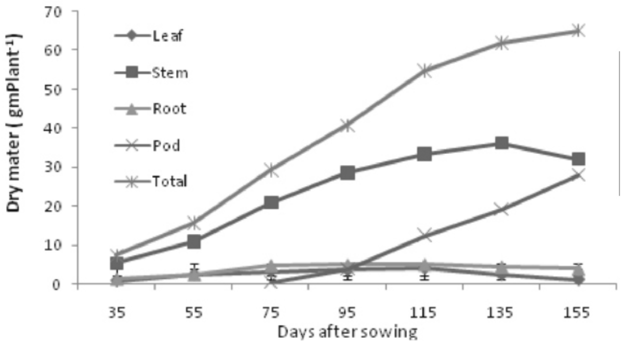
Dry mater partitioning of various parts of RH-30 under FACE and irrigated condition



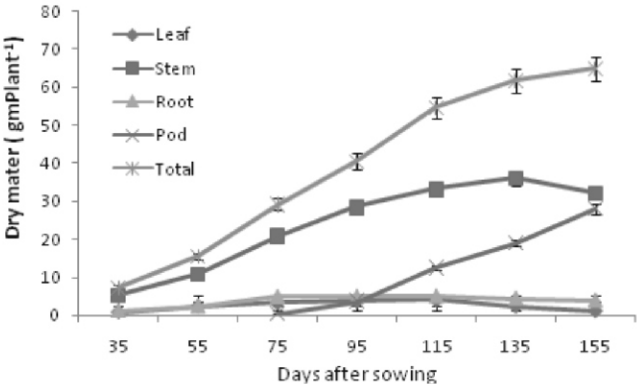
Dry mater partitioning of various parts of RH-30 under FACE and drought condition



Dry mater partitioning of various parts of RH-30 under FACE and drought condition



Dry mater partitioning of various parts of RH-30 under AMB and irrigated condition



Dry mater partitioning of various parts of RH-30 under AMB and drought condition

Fig. 2. Interactive effect of elevated CO2 and moisture stress on dry matter distribution o leaves, stem, root, pod and total dry weight of *cv.* RH-30

References

Abd Elgawad, H., Zinta, G., Beemster, G.T.S., Janssens, I.A., Asard, H., 2016. Future climate CO_2 levels mitigate stress impact on plants: increased defense or dcreased challenge? Front. Plant Sci. 7, 556. https://doi.org/10.3389/fpls.2016.00556.

Ainsworth, E.A., Long, S.P., 2004. What have we learned from 15 years of free air CO_2 enrichment (FACE)? A meta-analytic review of the response of photosynthesis, canopy properties and plant production to rising CO_2. New Phytol. 165, 351-372

Amthor, J.S. 1989. Respiration and Crop productivity. Springer-Verlag, Berlin.

Amthor, J.S. 1994. Plant respiratory responses to the environment and their effects on the carbon balance. In : Wilkinson, RE (ed.) Plant environment Interactions pp. 501-54 Marcel Dekker, New York.

Avilaa R.T., de Almeidaa W.T. , Costaa L.C., Machadoa KLG, Barbosaa M.L., de Souzaa R.P.B. , Martinoa P.B., Juáreza M.A.T., Marçala D.M.S., Martinsa S.C.V. , Ramalhob DC. , DaMattaa, F.M. 2020 Elevated air CO2] improves photosynthetic performance and alters biomass accumulation and partitioning in drought-stressed coffee Environmental and Experimental Botany 177 104137 plantshttps://doi.org/10.1016/j. envexpbot.2020.104137

Bunce, J.A. 1995a. The effect of carbon dioxide concentration on respiration of growing and mature soybean leaves. Plant Cell Environ. 18: 575-581.

Bunce, J.A. 1995b. Effects of elevated carbon dioxide concentration in the dark on the growth of soybean seedlings. Ann. Bot. 75: 365-368.

Das Ranjan 2020 Study on Growth Characteristics of Some Brassica Species under Moisture Stress and Elevated Carbondioxide International Journal of Environment and Climate Change 10(12): 373-389, 2020; Article no.IJECC.64843 ISSN: 2581-8627 (Past name: British Journal of Environment & Climate Change, Past ISSN: 2231-4784) DOI: 10.9734/IJECC/2020/v10i1230313

De Costa, W. A. J. M.; Weerakoon, W. M. W.; Herath, H. M. L. K.; Amaratunga, K. S. P. and Abeywardena, R. M. I. 2006. Physiology of yield determination of rice under elevated carbon dioxide at high temperatures in a subhumid tropical climate. Field Crops Research96(2): 336-347.

Gardener, F.P., Pearce, R.B. and Mitchel, R.L. 1985. Physiology of Crop Plants. The Iowa State University Press. Ames.

He, L., Cleverly, J., Wang, B., Jin, N., Mi, C., Liu, D.L., Yu, Q., 2017. Multi-model ensemble projections of future extreme heat stress on rice across southern China. Theor. Appl. Climatol. 133, 1-12.

Imai, K. 1995. Physiological response of rice to carbon dioxide temperature and nutrients. In : Peng, S. Ingram K.T., Neue HU. Ziska L.H. (eds) Climate Change and Rice pp 252-7, IRRI, Springer-Verlag, Berlin, Heidelberg.

IPCC 2014 (Intergovernmental Panel on Climate Change) Climate change. Synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change, the core writing team, Pachauri RK, Meyer LA. Geneva: IPCC. 2014;40-54.

IPCC. 2013. In Stocker TF, Qin D, Plattner GK, Tignor MMB, Allen SK, Boschung J, et al. (Eds.), Climate Change: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK;

Kim, M.; Kim, S.; Kim, S. and Kim, B.D. (2001). Isolation of cDNA clones differentially accumulated in the placenta of pungent pepper by suppression subtractive hybridization. Mol. Cells11(2): 213-9.

Liu, B., Liu, L., Tian, L., Cao, W., Zhu, Y., Asseng, S., 2014. Post-heading heat stress and yield impact in winter wheat of China. Glob. Chang. Biol. 20, 372-381.

Liu, S.R., Barton, C., Lee, H., Jarvis, P.G., Durrant, D., Jiang, Ze Hui. (Ed.), Centritto, M. (ed.), Liu, S.R. (ed.) and Chiatante, D. 2002. Long-term response of Sitka spruce (Picea sitchensis (Bong.) Carr.) to CO2 enrichment and nitrogen supply. I. Growth, biomass allocation and physiology. International conference on Forest ecosystems: ecology, conservation and sustainable management, Chengdu, China, 15-21 August 2000. Plant-Biosystems. 2002, 136: 189-198.

Long, S.P., 1991. Modification of the response of photosynthetic productivity to rising temperature by atmospheric CO2 concentrations: has its importance been underestimated? Plant Cell Environ. 14, 729-739.

Masuya, Y. Kumagai1,E ; Matsunami, M ; Shimono, H, 2020 Dry matter partitioning to leaves differentiates African and Asian rice genotypes exposed to elevated CO2J Agro Crop Sci. 2021;207:120-127 DOI: 10.1111/jac.12445

Pang, J., Zhu, J., Xie, Z., Liu, G., Zhang, Y., 2006. A new explanation of the N concentration decrease in tissues of rice (Oryza sativa L.) exposed to elevated atmospheric p CO2. Environ. Exp. Bot. 57, 98-105.

Peng, S., Huang, J., Sheehy, J.E., Laza, R.C., Visperas, R.M., Zhong, X., Centeno, G.S., Khush, G.S., Cassman, K.G., 2004. Rice yields decline with higher night temperature from global warming. Proc. Natl. Acad. Sci. 101, 9971-9975.

Riviere-Rolland, H., Contard, P. and Betsche, T. 1996. Adaptation of pea to elevated atmospheric CO2: Rubisco phosphoenol pyruvate carboxylase and chloroplast phosphate translocator at different levels of nitrogen and phosphorus nutrition. Plant Cell Environ. 19: 109-117.

Rodrigues, W.P., Martins, M.Q., Fortunato, A.S., Rodrigues, A.P., Semedo, J.N., SimoesCosta, M.C., Pais, I.P., Leitão, A.E., Colwell, F., Goulão, L., Máguas, C., Maia, R., Partelli, F.L., Campostrini, E., Scotti-Campos, P., Ribeiro-Barros, A.I., Lidon, F.C., DaMatta, F.M., Ramalho, J.C., 2016. Long-term elevated air [CO2] strengthens photosynthetic functioning and mitigates the impact of supra-optimal temperatures in tropical Coffea arabica and Coffea canephora species. Glob. Chang. Biol. 22, 415-431. https://doi.org/10.1111/gcb.13088.

Segura-Perez, M.L., Parra, J.F., Lorenzo, P., Sanchez-Guerrero, M.C., Medrano, E. and Fernandez-J.A. 2001. Martinez, P.F, Castilla, N. 2001. The effects of CO2 enrichment on cucumber growth under greenhouse conditions. Proceedings of the Fifth International Symposium on Protected Cultivation in Mild Winter Climates: Current Trends for Sustainable Technologies, Cartagena-Almeria, Spain, and 7-11 March 2000. Vol. 1. Acta-Horticulture. 2001, No.559, 217-222.

Srivastava A.C., Pal M., Das M., Sengupta U.K. 2001: Growth, CO2 exchange rate and dry matter partitioning in mung bean (Vigna radiata L.) grown under elevated CO2. Indian J. Exp. Biol., 39: 572-577.

Suter, D., Frehner, M. Fischer, B.U., Nosberger, J. and Luscher, A. 2002. Elevated CO2 increases carbon allocation to the roots of Lolium perenne under free-air CO2 enrichment but not in a controlled environment. New Phytol. 154: 65-75.

Thurling, N.W. 1974. Morpho-physiological determinants of yield in rapeseed (Brassica campestris and B. napus) I. Growth and morphological characters. Aust J. Agric. Res. 25: 679-710.

Vanaja, M. Ratnakumar, P. Vagheera, P. Jyothi, M , Raghuram . P. R. Reddy , Jyothi N.L, Maheshwari, M. Yadav S.K. 2006 Initial growth responses of blackgram (Vigna mungo L. Hepper) under elevated CO2 and moisture stress PLANT SOIL ENVIRON., 52, 2006 (11): 499-504

Wang, J., Wang, C., Chen, N., Xiong, Z., Wolfe, D., Zou, J., 2015. Response of rice production to elevated CO2 and its interaction with rising temperature or nitrogen supply: a meta-analysis. Clim. Change 130, 529-543.

Wullschleger, S.D. and Norby, R.J. 2001. Sap velocity and canopy transpiration in a sweetgum stands exposed to free air CO2 enrichment (FACE). New Phytol. 150: 489-498.

Xu, C., Wu, W., Ge, Q., 2018. Impact assessment of climate change on rice yields using the ORYZA model in the Sichuan Basin. China. International Journal of Climatology 38, 2922-2939..

Zhang, J., Feng, L., Zou, H., Liu, D.L., 2015. Using ORYZA2000 to model cold rice yield response to climate change in the Heilongjiang province. China. Crop Journal 3, 317-327.