Journal of Agrometeorology 12 (1): 1-7 (June 2010)

Effect of diurnal variation of atmospheric and elevated levels of carbon-di-oxide and photosynthetically active radiation on intercellular concentration and rate of photosynthesis in maize and safflower

M.RAJAVEL, R.P.SAMUI, L.S.RATHORE, R.BALASUBRAMANIAN, K.GHOSH and N.CHATTOPADHYAY
Agricultural Meteorology Division, India Meteorological Department, Pune-5
E-mail: m_rajmet@yahoo.co.in

ABSTRACT

A field experiment was conducted during rabi 2003 to study the effect of elevated levels of CO_2 and PAR on intercellular CO_2 concentration (C_i), net photosynthetic rate and their interrelationship in maize and safflower at different growth stages. The highest concentration of intercellular CO_2 was recorded at 1200 and 1400 hrs and lowest concentration of intercellular CO_2 was found during early hours in the morning (08 00 hours) irrespective of levels of CO_2 and PAR at all the stages of maize and sunflower. The higher rate of net photosynthetic rate was observed in active vegetative stage (11.7 to 49.1 µmol CO_2 cm^{-2} sec^{-1}) compared to knee high and flowering stages of maize and during late vegetative stage (21.6 to 47.2 µmol CO_2 cm^{-2} sec^{-1}) in safflower compared to early vegetative and flowering stage. The optimum levels of CO_2 and PAR for maize were 650µmol CO_2 mol^{-1} and 960 µmol m^{-2} s^{-1} respectively and for safflower were 650µmol CO_2 mol^{-1} and 1100 µmol m^{-2} s^{-1} respectively. A combination of 650 µmol CO_2 mol^{-1} and 960 µmol m^{-2} s^{-1} of PAR for maize and 650 µmol CO_2 mol^{-1} and 1100 µmol m^{-2} s^{-1} of PAR for safflower were found optimum levels. A positive correlation between the intercellular CO_2 concentration and net photosynthetic rate in maize and safflower was found throughout the crop growth period.

Key words : CO_2,PAR, intercellular CO_2 concentration, net photosynthetic rate

Green plants need CO_2 to grow and a higher concentration of atmospheric CO_2 will stimulate the photosynthetic process, promoting plant growth and agricultural productivity without increasing the water demand for crop transpiration (Goudriaan and Unsworth, 1980). On the other hand, expected climatic warming may have adverse effects on agriculture, partly off setting the positive direct CO_2 effects. Models predict that the global temperature will rise by about 1-3.5 ^{0}C by the year 2100.

In general, the change in crop yields depends not only on the change in rainfall but also change in CO_2 concentration, PAR and temperature. While increase in the rainfall and concentration of CO_2, generally lead to an increase in yield, the impact of an increase in temperature is generally negative in tropics. Thus, it is necessary to ascertain whether the impact of increased rainfall and CO_2 will overcome the impact of increased temperature.

Plant shoot responses to elevated CO_2 are well documented. Previous work has shown that high CO_2 often changes plant water use efficiency, net photosynthesis, biomass production and yield (Carlson and Bazzaz, 1980; Rogers and Dahlman, 1993; Amthor, 1995). In general, under elevated CO_2, whole plant nutrient uptake and nutrient utilization efficiency decline (Rogers et al., 1994, 1997). When other environmental resources are present in adequate levels, CO_2 can enhance photosynthesis of C_3 plant over a wide range of concentrations.

Several studies have been made in glasshouses, control environmental chambers and open fields on the short and long term effects of elevated atmospheric CO_2 concentration (Ca) on native and cultivated plants species (Devakumar and Jacob,1997 ; Drake et al.,1997; Jacob et al., 2001; Long et al., 2004; Norby et al., 1999). Leaf photosynthetic rate directly responds to changes in intercellular CO_2 concentration (C_i) (Jacob et al.,1995). In general, C_3 plant shows more response than C_4 and CAM plants.

Studies on relationship between light intensity and photosynthetic rate in rose plant suggests that 1200- 2000 foot candles light intensity was a light saturation range for most plants and CO_2 saturation range for most plants is 500-1000 ppm while the ambient CO_2 level being 350 ppm in the atmosphere. The leaves of shaded tomato plants show a higher stomatal conductance and higher intercellular CO_2 concentration (Xianzhaoliu et al., 2002). Therefore, the present study was conducted with the objective to quantify the effect of diurnal variation of atmospheric and elevated levels of Carbon-di-oxide (CO_2) and Photosynthetically Active Radiation (PAR) on intercellular CO_2 concentration and rate of photosynthesis in C_4 (maize cv. Panchaganga) and C_3 (safflower cv. Phule kusuma) crops.

MATERIALS AND METHODS

The experiment was conducted at College of Agriculture, Pune during rabi 2003 season in maize cv.

Panchganga (a C_4 crop) and safflower cv. Phule Kusuma (a C_3 crop). Net photosynthetic rate (A), atmospheric CO_2 concentration, intercellular CO_2 (C_i) concentration, photosynthetically active radiation were measured using portable photosynthesis system-an open system (LI- 6400, LI-COR, Lincoln) at two hourly intervals viz. 0800, 1000, 1200, 1400, 1600 hours IST. The measurements were taken at different levels of CO_2 concentrations (atmospheric level, 550, 650 µmol CO_2 mol^{-1}) and PAR (atmospheric, 800, 1100 µmol m^{-2} s^{-1}). The observations were taken after the instruments had been configured and calibrated. The analyzer pump and fans were turned on and CO_2 and relative humidity channels are put in the display. The chamber was clamped on a leaf similar to those to be measured. Until the relative humidity is steady at ambient value, the flow is adjusted and the chamber was clamped on to the third fully opened leaf from the tip. After waiting for an appropriate interval, log button was pressed on the console; when a steady CO_2 draw down is observed.

In order to supply elevated levels of CO_2 in side the leaf chamber, CO_2 cartridges (12 g) filled with CO_2 fitted to the CO_2 tank, encompasses injector system (6400-01) which consists of an electronic controller. Using CO_2 injector system a constant CO_2 input viz. 550/650 µmol CO_2 mol^{-1} was passed to the leaf chamber. The CO_2 is controlled by delivering a precisely controlled pure CO_2 stream into air that is CO_2 free. Four minutes was allowed for CO_2 mixing. The 6400-02 LED light source which is totally integrated with the hardware and software of the LI-6400 system was used to supply different levels of PAR. The LED light source is installed by replacing the upper half of the standard LI-6400 leaf chamber, which are used for making measurements at atmosphere PAR. When using the standard leaf chamber, PAR is measured in the chamber near the leaf plane using the miniature gallium arsenide phosphide (GaAsP) sensor. The external ambient Photosynthetically Active Radiation was measured with an optional LICOR quantum sensor located outside the chamber. Incoming air was not scrubbed for water vapour. Before making each measurement, Infra Red Gas Analysers (IRGAs) were matched.

RESULTS AND DISCUSSION

Diurnal variation of intercellular CO_2 concentration (C_i)

Two hourly variations of intercellular CO_2 concentration of maize and sunflower are presented in the Figs. 1 & 3. Increased supply of CO_2 and light improved the CO_2 concentration in inter cellular spaces of leaf cells at all the three stages of maize growth. The highest intercellular CO_2 concentration (220.66 µmol CO_2 mol^{-1}) was recorded at 1400 hrs. After 1400 hrs, intercellular CO_2 concentration started declining. The lowest CO_2 concentration was observed at 0800 hrs. Increasing external CO_2 supply caused increase in CO_2 concentration and higher CO_2 concentration (215.55 µmol CO_2 mol^{-1}) as observed in 550 µmol CO_2 mol^{-1} compared to 650 µmol CO_2 mol^{-1} and atmospheric CO_2. Additional supply of light compared to natural level has given increased CO_2 concentration in the intercellular spaces differentially in a day. At the beginning of the day (0800 hrs) when the natural PAR were 1060.5, 159.7 and 196.2 µmol m^{-2} s^{-1}, during knee-high, active vegetative and flowering stages respectively, increased levels of light viz., 800 and 1100 µmols m^{-2} s^{-1} had increased CO_2 concentration. But as the day progresses, even with natural supply of light higher intercellular CO_2 concentration was observed at all the growth stages. 1100 µmol m^{-2} s^{-1} level of light had resulted in higher intercellular CO_2 concentration of 170.4 µmol CO_2 mol^{-1} and 162.31 µmol CO_2 mol^{-1} during knee-high and flowering stages compared to 800 µmol m^{-2} s^{-1}. The optimum level of CO_2 for maize was 550 µmol CO2 mol^{-1} and PAR was 960 µmol m^{-2} s^{-1} and a combination of 650µmol CO_2 mol^{-1} and 960 µmol m^{-2} s^{-1} of PAR is found to be optimum.

Similar effect of elevated CO_2 levels has also seen in intercellular CO_2 concentration in safflower. The highest intercellular CO_2 concentration (232.04 µmol CO_2 mol^{-1}) was recorded at 1400 hrs., thereafter intercellular CO_2 concentration started declining as in maize. The lowest CO_2 concentration (208.47 µmol CO_2 mol^{-1}) was observed at 0800 hrs compared to 1000 to 1600 hrs. Increased CO_2 supply of 650 µmol CO_2 mol^{-1} recorded higher intercellular CO_2 concentration (234.75 µmol CO^2 mol^{-1}) compared to atmospheric CO_2 and 550 µmol CO_2 mol^{-1}. Though supply of light favours increased intercellular CO_2 concentration at 0800 hrs., it failed to improve the intercellular CO_2 concentration beyond 0800 hrs. due to the higher natural PAR as the day progresses. The intercellular CO_2 concentration at 0800 hrs. was lower at all the growth stages of safflower compared to 1000 to 1600 hrs. The optimum level of CO_2 for safflower was 650 µmol CO_2 mol^{-1} and PAR was 1100 µmol m^{-2} s^{-1} and a combination of 650µmol CO_2 mol^{-1} and 1100 µmol m^{-2} s^{-1} of PAR is found to be optimum.

Diurnal variation of net photosynthetic rate at different levels of CO_2 and PAR

The effects of elevated levels of CO_2 and PAR on net photosynthetic rate of maize and safflower are depicted in Figs. 2 & 4. The elevated levels of CO_2 supply and PAR enhanced the net photosynthetic rate of maize. The net photosynthetic rate was higher (33.89 µmol CO_2 cm^{-2} sec^{-1}) in 650 µmol CO_2 mol^{-1} compared to atmospheric CO_2 and 550 µmol CO_2 mol^{-1}. Ziska et al. (1999) also found increased photosynthetic carbon fixation in C_4 species as the

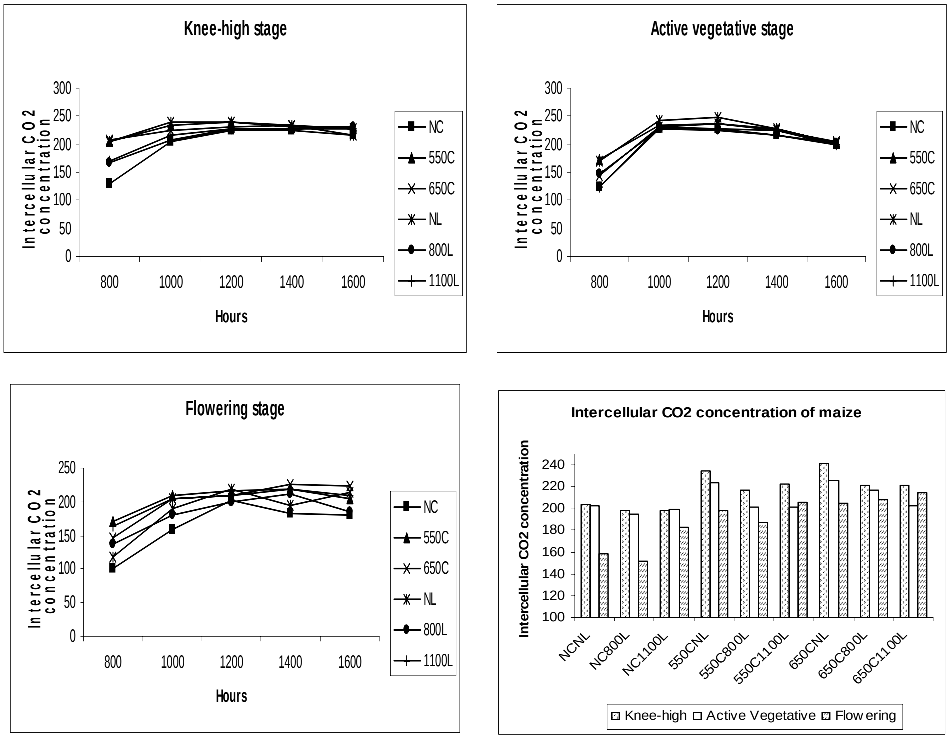

Fig.1: Effect of elevated levels of CO_2 and PAR on intercellular CO_2 concentration (µmol CO_2 mol^{-1}) in maize

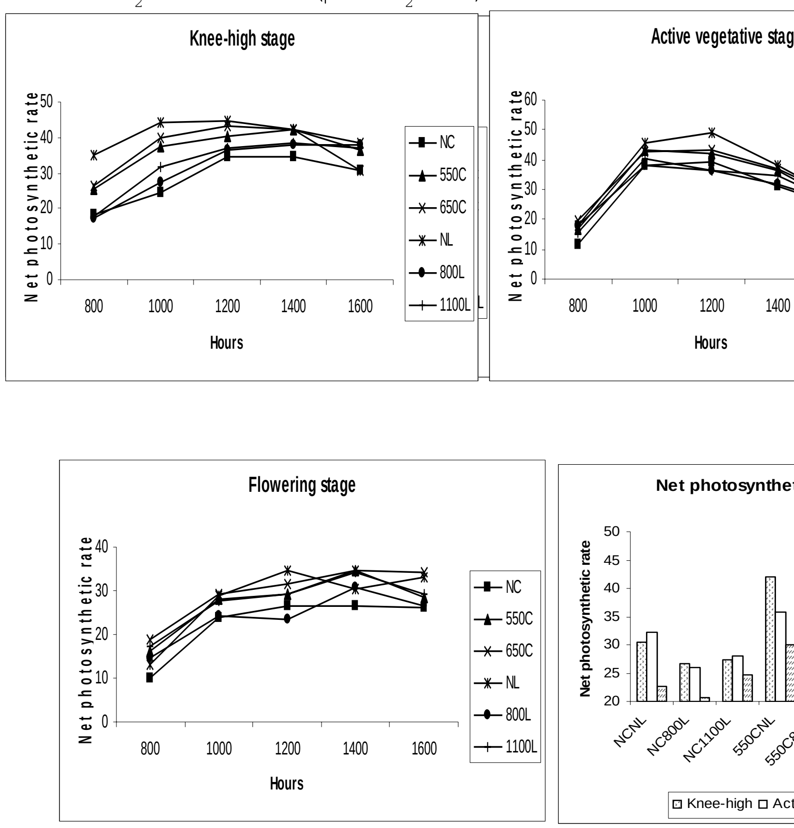

Fig.2: Mean net photosynthetic rate (µmol CO_2 cm^{-2} sec^{-1}) as influenced by CO_2 and PAR in maize

Fig.3: Effect of elevated levels of CO_2 and PAR on intercellular CO_2 concentration (µmol CO_2 mol^{-1}) in safflower

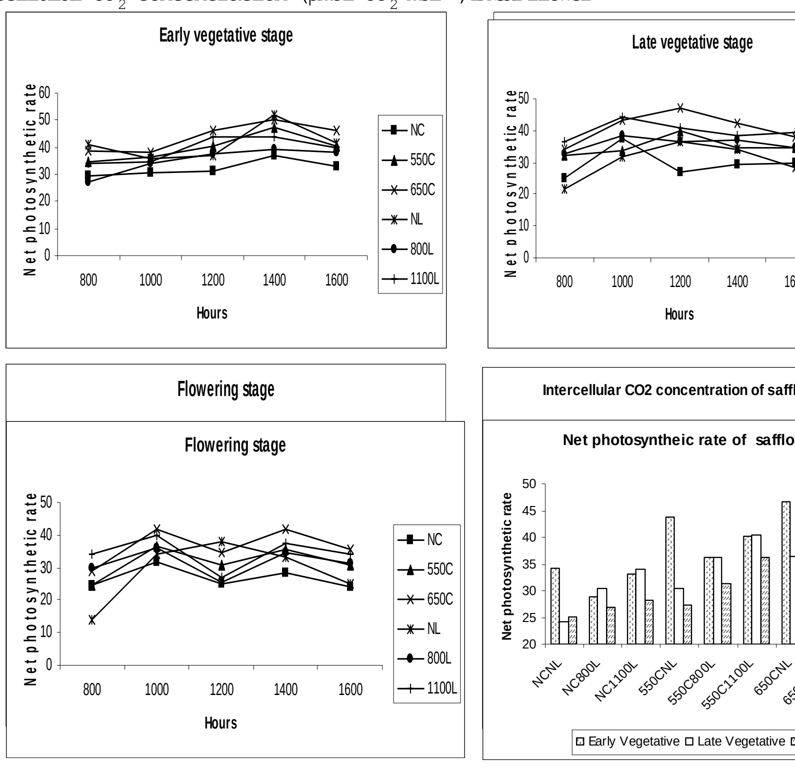

Fig.4: Mean net photosynthetic rate (µmol CO_2 cm^{-2} sec^{-1}) as influenced by CO_2 and PAR in safflower

atmospheric CO_2 concentration rises, under moderate to high light regimes. Increasing the supply of PAR from 800 and 1100 µmol $m^{-2} s^{-1}$ has increased the net photosynthetic rate with variable effects in a day. At the beginning of the day at 0800 hrs increased levels of PAR viz., 800 and 1100 µmol $m^{-2} s^{-1}$ has increased net photosynthetic rate at flowering stage only but at knee-high and active vegetative stage, natural supply of PAR itself recorded highest net photosynthetic rate. As the day progresses, even with natural supply of PAR higher rate of net photosynthetic rate was observed. External supply of 1100 µmol $m^{-2} s^{-1}$ level of light has recorded higher net photosynthetic rate compared to 800 µmol $m^{-2} s^{-1}$. Assimilation of CO_2 depends on the photo flux incident upon the canopy and its absorption by leaves in different layers and on the efficiency of conversion of assimilate (Lawlor, 2001).

The higher rate of net photosynthetic rate was observed in knee-high stage of maize compared to active vegetative and flowering stages. The lower photosynthetic rate during later stages of crop growth is due to ageing of leaf and decline in photosynthetic efficiency. Similar relationship between rate of leaf area development and rate of photosynthetic rate was reported earlier by Muramoto et al. (1988).

Similar effect in safflower also noticed due to elevated levels of CO_2 and light. Supply of 650 µmol CO_2 mol^{-1} have recorded highest net photosynthetic rate than atmospheric and 550 µmol CO_2 mol^{-1}. In the morning at 0800 hrs, increased levels of PAR viz., 800 and 1100 ìmol $m^{-2} s^{-1}$ have increased the net photosynthetic rate of safflower even at late vegetative (32.9 and 36.7 µmol CO_2 cm^{-2} sec^{-1} respectively at 800 and 1100 µmol $m^{-2} s^{-1}$ and flowering stages (30.0 and 34.3 µmol CO_2 cm^{-2} sec^{-1} respectively at 800 and 1100 µmol $m^{-2} s^{-1}$. However, as the day progresses, net photosynthetic rate of safflower at elevated levels of PAR is lesser than atmospheric PAR. The highest rate of net photosynthetic rate is observed during early vegetative stage and beyond which photosynthetic rate declines. At all the stages, net photosynthetic rate was highest between 1000 to 1400 hrs. irrespective of the growth stages.

Effect of elevated levels of CO_2 and PAR on ratio of C_i/C_a

Increased supply of CO_2 (550 and 650 µmol CO_2 mol^{-1}) and PAR (800 and 1100 ìmol $m^{-2} s^{-1}$) enhanced the ratio of C_i/C_a at all the stages of maize. Increased ratio of C_i/C_a was observed with increased CO_2 concentration of 550 µmol CO_2 mol^{-1} (0.55) and 650 µmol CO_2 mol^{-1} (0.57) compared to atmospheric CO_2. The highest ratio of C_i/C_a was noticed at 1200 hrs (0.60) and 1400 hrs (0.60) in maize and thereafter the ratio was declined. The ratio of C_i/C_a was lowest (0.38) at 0800 hrs. Additional supply of PAR compared to natural PAR has given increased ratio of C_i/C_a in early hours (0.54) at 0800hrs in the morning at flowering stage. The ratio of C_i/C_a was higher with atmospheric PAR at knee- high (0.59) and active vegetative (0.54) stages indicating the sufficiency of natural PAR. At 1000, 1200 and 1400 hrs, the ratio of C_i/C_a was highest in atmospheric PAR in comparison with 800 and 1100 mol $m^{-2} s^{-1}$. Similar response is noticed in safflower also. Increased CO_2 concentration of 650 µmol CO_2 mol^{-1} have resulted in increased ratio of C_i/C_a (0.62) compared to atmospheric CO_2 and 550 µmol CO_2 mol^{-1}. The ratio of C_i/C_a was lowest at 0800 hrs. at all the growth stages of safflower. The highest ratio of C_i/C_a was noticed at 1400 hrs. (0.63), therafter, ratio of C_i/C_a started declining. Additional supply of PAR compared to natural PAR has given increased ratio of C_i/C_a early hours (0800hrs) in the morning at late vegetative(0.52) and flowering(0.53) stage. While at early vegetative stages ratio of C_i/C_a (0.59) was higher in atmospheric PAR. At 1000, 1200 and 1400 hrs, the ratio of C_i/C_a was highest in atmospheric PAR in comparison with 800 and 1100 mol $m^{-2} s^{-1}$. The conductance of the leaf surface and the rate of photosynthesis determine the concentration of CO_2 in the intercellular spaces. CO_2 concentration at cell surface is the effective supply of CO_2 which the assimilating cells experience within the leaf. The CO_2 concentration of the intercellular spaces depends on the geometry of the mesophyll air spaces (Lawlor, 2001).

Inter relationship between net photosynthetic rate and intercellular CO_2 concentration

The flux of CO_2 from the cell surface to Rubisco, consists of a series of 'resistances' in the liquid phases of the cell wall, cell membrane, cystol, chloroplast membranes and stoma to the enzyme active site. The rate of CO_2 assimilation is not a linear function of C_i or of the activity of Rubisco, but reaches a plateau at higher rate of the net photosynthesis, which may be explained by a 'draw- down' of CO_2 at the active site at high photosynthesis, even if C_i is large (Lawlor, 2001). If leaf conductance to the flux of the CO_2 is some 30% below that of the intercellular space under normal atmospheric conditions (Van caemmerer and Evans, 1991). The carboxylation efficiency (ìmol CO_2 assimilation $m^{-2} s^{-1} Pa^{-1}$) may be calculated from the slope of the relation between A and C_i when A is zero. Carboxylative efficiency is related to metabolism, with C_3 plants having smaller efficiency than C_4 plants, and it depends on the amount of Rubisco in the tissue, for example nitrogen deficiency decreases both Rubisco amount and activity also efficiency in C_3 and C_4 plants. In the present experiment, a significant positive correlation exists between the intercellular CO_2 concentration and net photosynthetic rate. The linear relationship observed is furnished in Table 1.

Table 1: Correlation coefficient, regression equation for intercellular CO_2 concentration (C_i) and net photosynthetic rate (A)

Crop	Stage of the crop	r	Regress
Maize	Knee-high	0.95*	A= 0.38 R^2 = 0.9
	Active vegetative	0.89**	A= 0.30 R^2 = 0.7
	Flowering	0.85**	A= 0.15 R^2 = 0.7
Safflower	Early vegetative	0.99*	A= 0.62 R2 = 0.9
	Late vegetative	0.96*	A = 0.33 R^2 = 0.9
	Flowering	0.90**	A= 0.29 R^2 = 0.8

*Significant at 1% level ** Significant at 5% level

CONCLUSION

(i) Diurnal variation of intercellular CO_2 concentration indicated that the highest intercellular CO_2 concentration was recorded during 1200 hrs in maize (220.66 μmol CO_2 mol^{-1}) and 1400 hrs. in safflower (232.04 μmol CO_2 mol^{-1}) under natural condition.

(ii) Atmospheric PAR supply of 960 μmol m^{-2} s^{-1} recorded highest intercellular CO_2 concentration in maize (205.44 μmol CO_2 mol^{-1}) and external supply of 1100 μmol m^{-2} s^{-1} level of PAR recorded highest intercellular CO_2 concentration in safflower (228.45 μmol CO_2 mol^{-1}).

(iii) External supply of 550 μmol CO_2 mol^{-1} has resulted in highest intercellular CO_2 concentration in maize (215.55 μmol CO_2 mol^{-1}) and 650 μmol CO_2 mol^{-1} has resulted in highest intercellular CO_2 concentration (234.75 μmol CO_2 mol^{-1}) in safflower.

(iv) The optimum level of CO_2 for higher net photosynthesis of maize was 650 μmol CO_2 mol^{-1} and PAR was 960 μmol m^{-2} s^{-1} and for safflower was 650 μmol CO_2 mol^{-1}, PAR of 1100 μmol m^{-2} s^{-1}. A combination of 650μmol CO_2 mol^{-1} and 960 μmol m^{-2} s^{-1} of PAR for maize and 650 μmol CO_2 mol^{-1} and 1100 μmol m^{-2} s^{-1} of PAR were found to be optimum levels.

(v) Increased supply of 650 μmol CO_2 mol^{-1} enhanced the ratio of C_i/C_a at all the stages of maize (0.57) and sunflower (0.62).

(vi) Intercellular CO_2 concentration and net photosynthetic rate is positively and significantly correlated.

(vii) The results of the study would help to utilize natural resources and also to tackle problem related to global warming under increased green house gases.

ACKNOWLEDGEMENT

The authors express their sincere thanks to AVM (Dr.) Ajit Tyagi, Director General of Meteorology, IMD for according permission to publish the paper in the journal of Agrometeorology.

REFERENCES

Amthor, J.S., (1995). Terrestrial higher-plant response to increasing atmospheric CO_2 in relation to the global carbon cycle. Glob. Change Biol. 1: 243-74.

Carlson, R.W., and Bazzaz, F.A., (1980). The effects of elevated CO_2 concentration on growth, photosynthesis, transpiration and water use efficiency of plants. In: Environment and Climatic Impact of Coal Utilization, Singh, J. and Deepak, A. (eds). Academic Press, New York. pp. 609-12.

Devakumar, A.S. and Jacob, J., (1997). Growth and Development of plants in a CO_2 enriched World. Agro's Ann.Rev. Pl. Physiol., pp. 281-317.

Drake, B.G. and Gonzalex-Meler, M.A., (1997). More efficient plants: A consequence of rising atmospheric CO_2. Ann. Rev. Plant Physiol. Plant Mol. Biol., 48: 609-39.

Goudriaan, J. and Unsworth, M.H., (1990). Implications of increasing carbon dioxide and climate change for agricultural productivity and water resources. In: Impact of carbon dioxide, trace gases and climate change on global agriculture. American Society of Agronomy (ASA), Madison, WI, USA, Special publication No.53, pp. 111-130

Jacob, J., Devakumar, A.S. and Drake, B.G., (2001). Global climate change and productivity. In: Tropical Forestry Research: Challenges in the millennium.

Varma, R.V., Bhat, K.V., Muralidharan, E.M. and Sharma, J.K. (Eds.), Proceedings of the International Symposium, August 2-4, 2000. Peechi. India, pp.131-136.

Jacob J., Grieter, C. and Drake, B.G., (1995). Acclimation of photosynthesis in relation to Rubisco and non-structural carbohydrate contents and in situ carboxylase activity in Scirpus olnei grown at elevated CO_2 in the field. Plant. Cell Environ., 18: 875- 884.

Kozaki, A. and Takeba, G. (1996). Photorespiration protects C_3 plant from photooxidation. Nature, 384: 557-560.

Lawlor, D.W., (2001). Carbon dioxide supply for photosynthesis. In: Photosynthesis, Viva Books Pvt. ltd. pp.386.

Long, S.P, Anisworth, E.A., Rogers, A. and Ort, D.R., (2004). Rising atmospheric carbon dioxide: Plant face the future. Annu.Rev. Plant Biol., 55: 591-628.

Muramoto, H., Hasketk, J., and El- Sharkawy, M., (1988). Relationship among rate of leaf area development, photosynthetic rate and rate of dry matter production among american cultivated cotton and other species. Crop Sci., 28: 163-166.

Norby, R.J., Wullschleger, S.D., Gnnderson, C.A., Johnson, D.W. and Cenlemans, R., (1999). Tree responses to rising CO_2 in field experiments: Implications for the future forest. Plant Cell Environ., 22: 683-714.

Rogers, H.H. and Dahlman, R.C., (1993). Crop responses to CO_2 enrichment. Vegetation, 104/105:117-31.

Rogers, H.H., Runion, G.B. and Krupa, S.V., (1994). Plant responses to atmospheric CO_2 enrichment with emphasis on root and rhizosphere. Environ. Pollution, 83:155-89.

Rogers, H.H., Runion, G.B., Prior, S.A. and Tobert, H.A., (1997). Responses of plant to elevated atmospheric CO_2: Root growth, mineral nutrition and soil carbon. In: Carbon dioxide and environmental stress, Seemann, J.R., Lno, V and Moony, H.A., (eds.), San Diego, CA, Academic Press.

Von caemmerer, S. and Evans, J.R., (1991). Determination of the average partial pressure of CO_2 in chloroplasts from leaves of several C_3 plants. Aust. J. Plant Physiol., 18: 287- 305.

Xianzhaoliu, Shaozhong Kang and Jianhua Zhang (2002). Yield and photosynthetic responses of tomato (Lycopersicon esulentum) to shading at different growth stages. Indian J. Agrl. Sci., 72(2):106-108

Ziska, L.H., Sicher, R.C. and Bunce, J.A., (1999). The impact of elevated CO2 on the and gas exchange of three C4 species differing CO2 leak rates. Physiologia Plantarum, 105: 74 - 80.

Received: September 2009; Accepted: November 2009