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Effect of Elevated CO_2 on Biomass Production, Photosynthesis and Carbon Sequestration of *Cenchrus ciliaris* and *Stylosanthes hamata* under Intercropping System

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ABSTRACT

Effect of elevated CO_2 (600±50 ppm) on biomass production, assimilatory functions and chlorophyll accumulation was studied in *Cenchrus ciliaris* + *Stylosanthes hamata* intercropping systems in open top chambers (OTCs) and in open field conditions. *C. ciliaris* + *S. hamata* produced 106% and 141% higher fresh and dry biomass respectively under elevated CO_2 (600±50 ppm). Rates of photosynthesis and stomatal conductance increased in both the crop species in intercropping systems under elevated CO_2 (600±50 ppm) over open grown crops. Due to increase in the rate of photosynthesis and leaf area index the canopy photosynthesis of these crop species increased significantly under elevated CO_2 over the open grown crops. The accumulation of chlorophyll a and b was also higher in the leaves of all crop species as grown in intercropping system in OTC with elevated CO_2 (600±50 ppm). The increased chlorophyll content, leaf area index and canopy photosynthesis led to higher growth and biomass production in these crop species under elevated CO_2. The total carbon sequestration during the three years by the crops (including soil C) was 19.73 Mg C/ha under elevated CO_2 (600±50 ppm). Therefore, this intercropping system indicated its potential as a sink for the increasing level of CO_2 in the atmosphere in the semi-arid tropics.

Keywords: *Biomass, carbon sequestration, Cenchrus ciliaris, photosynthesis, Stylosanthes hamata, transpiration*

1. INTRODUCTION

As CO_2 is the sole source of carbon for growth in plants, the response of photosynthesis and growth to increasing CO_2 has been the subject of a number of studies. Increased atmospheric CO_2 concentration and associated global warming are expected to alter growth rates and competitive relationships in pasture crops. The responses of grasses to CO_2 were reviewed by Wand *et. al.*, (1999). Although they reported growth enhancements of both C_3 and C_4 grasses from elevated CO_2 but greater responses were with C_3 grasses. While photosynthesis in C_4 plants can respond directly to elevated CO_2 above the present atmospheric concentrations (Le Cain and Morgan, 1998), the response is considerably more limited compared to that of C_3 species.

Finding low cost methods to sequester carbon is emerging as a major goal in the context of increasing concerns about global climate change. In this context rangelands may be a substantial global sink for atmospheric carbon dioxide. *Cenchrus ciliaris* and *Stylosanthes hamata* are perennial range grass and legume and cover large area under their production in tropical and sub tropical rainfed situation. These grass and legume species have not been assessed for their, growth behavior, biomass production, assimilatory functions and carbon sequestration under elevated CO_2 in the intercropping systems. Therefore, the present study has been undertaken on the long term effect of elevated CO_2 (60050 ppm) on growth, morphological and physiological attributes of Anjan grass (*Cenchrus ciliaris*) and Stylo (*Stylosanthes hamata*) in intercropping systems.

2. MATERIALS AND METHODS

Cenchrus ciliaris L. and *Stylosanthes hamata* Taub. were grown under intercropping system in three environmental conditions i.e. Open, Open Top Chamber (OTC) with ambient CO_2 (370-380 ppm) and Open Top Chamber with elevated CO_2 (60050 ppm) at IGFRI, Jhansi, India (25° N 78° E, 275 msl) during 2004-2006. Thirty days old seedlings of *Cenchrus ciliaris* were transplanted in these three environmental conditions inside the OTCs and in open field as control on the onset of monsoon i.e. in the month of July during every year. The stylo seeds were sown in between the rows of grass species at the time of transplanting of grass. The crop was managed throughout the growing season as per the recommended agronomical practices. The treatment of elevated CO_2 of 600 50 ppm in the OTCs was given after the establishment of grass and germination of stylo. The CO_2 cylinders were placed inside the control room in the manifold system and flow of gas was regulated and maintained by the regulators. Inside the OTCs the CO_2 concentration of 600 50 ppm was monitored through out the growth period of the crops by using Infra red Gas Analyzer (Photosynthesis systems) of CID, USA.

The assimilatory characters such as rate of photosynthesis (P_N), transpiration (T_R), stomatal conductance (Cs) and intercellular CO_2 concentration (Ci) were recorded in the second or third fully expanded leaf from the top of the plant grown under different environmental conditions by using portable photosynthesis system (LI-6200, LICOR, USA). All measurements were recorded between 11.00 and 12.00 hours on a clear sky day. The ratio P_N/TR (photosynthetic water use efficiency) was also calculated. Canopy photosynthesis was calculated by multiplying the rate of photosynthesis (P_N) with leaf area index (LAI) i.e., P_N X LAI at flowering stage of crop. Chlorophyll a, b, and total chlorophyll contents were determined by extraction in dimethylsulfoxide (DMSO), following non-maceration technique of Hiscox and Israelstam (1979). Soil organic carbon was estimated by Walkley and Black method (Jackson, 1973). Biomass production of *C. ciliaris* was recorded in two cuts at the interval of 60 days after regeneration. The stylo crop was harvested after120 days of growth along with second cut of *C. ciliaris.* Root biomass in both the crop species was also recorded after 120 days of growth. For taking the dry matter yield, the plant samples were dried in an electric oven at 80 °C for 48 hours. The leaf area was measured by an automatic leaf area meter (LICOR-3000, USA). LAI was calculated by dividing the total leaf area of one meter square with the land area occupied by the sample (Tanaka *et al.*, 1966). The organic carbon stock in soil at the depth of 0-15 cm was calculated as a product of depth of the soil x bulk density x % organic carbon content and expressed in Mega gram. Soil organic carbon content was determined in the start of experiment and also after 31 months at the time of harvesting the crop under all environmental conditions. For calculation of carbon sequestration in vegetation it has been assumed that the total dry biomass contain 50% carbon content. The total carbon sequestration is therefore calculated as the product of carbon content in vegetation + organic carbon stock in soil at the depth of 0-15 cm.

3. RESULTS AND DISCUSSION

Rate of photosynthesis (P_N) increased by 25% in *C. ciliaris* and 30% in *S. hamata* under elevated CO_2 (600±50 ppm) over open field grown crops of *C. ciliaris* (28.15 μmol/m^2/sec) and *S. hamata* (22.43 μmol/m^2/sec) in the intercropping system (Table 1). The increase in the rate of photosynthesis in *C. ciliaris* (C_4 plant) and *S. hamata* (C_3 plant) under elevated CO_2 (600±50 ppm) exhibit the potentials of these crop species towards higher P_N at higher level of CO_2. Similar to the rate of photosynthesis the stomatal conductance (C_S) was also recorded higher under elevated CO_2. The increasing in stomatal conductance under elevated CO_2 indicates that there is no effect of higher concentration of CO_2 on functioning of stomata. The increase in P_N and C_S in *C. ciliaris* under elevated CO_2 was also reported by Bhatt *et al,* (2007). The intercellular CO_2 concentration (Ci) was recorded higher in OTC with elevated CO_2 over open field grown crops. No significant effect of elevated CO_2 was observed on the rate of transpiration and P_N/TR ratio (photosynthetic water use efficiency) of both the crops.

Table 1. Effect of elevated CO^2 on assimilatory functions of *C. ciliaris+S. hamata* under different environmental conditions.

Treatments	PN (μ moles m^{-2} s^{-1})		CS (cm s-1)		TR (m moles m^{-2} s^{-1})		Ci (ppm)		PN/TR	
	C. ciliaris	*S. hamata*	*C. ciliaris*	*S. hamata*	*C. ciliaris*	*S. hamata*	*C. ciliaris*	*S. hamata*	*C. Ciliaris*	*S. hamata*
Open	28.15	22.43	0.93	0.87	11.42	9.90	265.70	255.20	2.46	2.26
OTC	31.65	23.86	1.37	1.06	13.10	10.65	330.15	316.70	2.42	2.24
OTC + CO2	34.92	29.12	1.59	1.19	13.76	12.18	495.85	545.50	2.54	2.39
CD at 5%	4.17	4.01	NS	0.077	NS	1.204	17.51	64.36	NS	NS

The canopy photosynthesis, which is calculated by multiplying the rate of photosynthesis with leaf area index (P_N x LAI) increased significantly in OTC with elevated CO_2. On average of all the three years canopy photosynthesis increased by 2.5 folds in *C. ciliaris* and 1.55 folds in *S. hamata* under elevated CO_2 (600±50 ppm) over the open field grown crops (Figure 1). Due to increase in leaf area index, the overall CO_2 assimilation increased significantly which has resulted higher biomass production under long term response of elevated CO_2. Baker *et. al.,* (2005) concluded that CO_2 enrichment significantly increased canopy photosynthetic rate. The higher canopy photosynthesis has maximized the growth and biomass production in these crop species under elevated Co_2.

The accumulation of chlorophyll a and b in both the crop species increased significantly under elevated CO_2 as compared to the open field grown crops (Table 2). The accumulation of chlorophyll a and b in *S. hamata* was relatively higher to that of *C. ciliaris* under all environmental conditions. The higher accumulation of chlorophyll a and b under elevated CO_2 in both the crop species probably

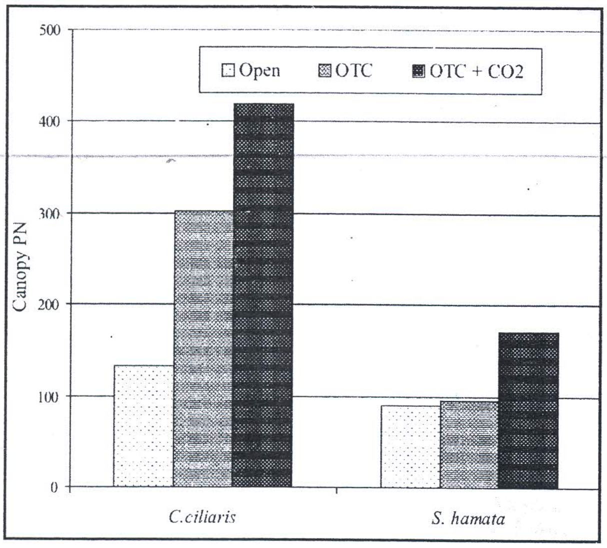

Fig. 1. Maximum probable Canopy photosynthesis (PN x LAI) of *C. ciliaris* and *S. hamata* under OTC with and without elevated CO_2 and in open field.

indicates the adaptation of these species at higher level of atmospheric CO_2. Total chlorophyll (chlorophyll a+b) was estimated higher by 1.26 fold in *C. ciliaris* and 1.31 fold in *S. hamata* under elevated CO_2. The increase in total chlorophyll accumulation predicts that there could be higher P_N under elevated CO_2 resulting higher growth and biomass production. Similar to our findings, Thomas and Sean (2005) reported increase in leaf chlorophyll content under elevated CO_2.

The cumulative biomass production (fresh and dry) in both the crop species under intercropping systems increased significantly in OTC with elevated CO_2. On average of three years *C. ciliaris* + *S. hamata* produced 3357.36 g/m^2 fresh biomass under elevated CO_2 which was 106% higher over the control (1627.20 g/m^2) (Table 3). Increased fodder productivity of white clover when grown under elevated CO_2 was also been reported by Saebo and Mortensen (1995). Similarly dry biomass production increased by 141% over the crops grown in open field (471.16 g/m^2). The increase in biomass production may be due to enhanced rate of photosynthesis and higher fixation of carbon and its allocation to the plant components. Elevated CO_2 stimulated total dry biomass accumulation which is a common physiological response to high CO_2 (Righetti *et. al.*, 1996). Steady increase of dry matter is a common physiological response to high CO_2 concentration (Atkinson *et. al.*, 1997).

Table 2. Effect of elevated CO^2 on photosynthetic pigments (mg g^{-1} fresh weight) of *C. ciliaris* and *S. hamata* under intercropping system.

Treatments	Chl a		Chl b		Chl a + b		Chl a: b	
	C. ciliaris	*S. hamata*	*C. ciliaris*	*S. hamata*	*C. ciliaris*	*S. hamata*	*C. ciliaris*	*S. hamata*
Open	1.17	1.74	0.12	0.25	1.29	1.99	10.06	7.05
OTC	1.33	2.17	0.14	0.37	1.47	2.54	9.64	5.83
OTC + CO2	1.47	2.21	0.16	0.41	1.63	2.62	9.00	5.33
CD at 5%	0.172	NS	0.027	0.049	0.175	0.453	NS	1.041

Table 3: Cumulative biomass production (gm^{-2}) in *Cenchrus ciliris*+ *S. hamata* under different environmental conditions during different years of growth.

Treatments	Fresh biomass production					Dry biomass production				
	1st year	2nd year	3rd year	Total	Average	1st year	2nd year	3rd year	Total	Average
Open	783.80	2490.00	1607.82	4881.62	1627.20	266.15	716.57	430.77	1413.49	471.16
OTC	2269.38	3146.66	2569.45	7985.49	2661.83	779.20	937.94	662.18	2379.32	793.10
OTC + CO_2	3375.01	3990.00	3307.07	10672.08	3357.36	1142.28	1315.32	952.27	3409.87	1136.62
CD at 5%	203.34	294.07	166.82	-	-	63.65	299.68	64.79	-	-

Initial soil organic carbon content was estimated to 0.45%. The soil organic carbon content increased in all the treatments over the years. The initial organic carbon stock in the soils of open top chambers (OTC) with or without elevated CO_2 and in open field showed variation ranging from 9.45 Mg C/ha to 10.57 Mg C/ha which was calculated at the soil depth of 0 to 15 cm having the bulk density of 1.5% (Table 4). After 31 months of crop growth during Ist, IInd and IIIrd years, the range of organic carbon stock was 12.10 Mg C/ha to 13.32 Mg C/ha. Although significant variation was not observed in different treatments but maximum organic carbon stock was estimated in the soil of OTC with elevated CO_2. There was increment in soil carbon stock of 2.65 Mg C/ha to 2.70 Mg C/ha after 31 months of crop growth. This indicated that the red soils (rakar) having the potential to sequester organic carbon during the period of crop growth.

On total of all the three years, the carbon content in these crops ranged from 7.06 Mg C/ha to 17.05 Mg C/ha. Total carbon sequestration in *C. ciliaris* + *S. hamata* intercropping systems was calculated by adding the values of carbon content of the biomass with organic carbon sequestration of the soil. Therefore, total carbon sequestration in C. *ciliaris* + *S. hamata* intercropping systems under different treatments ranged from 9.71 Mg C/ha to 19.73 Mg C/ha. Maximum carbon sequestration was calculated under elevated CO_2 (600±50 ppm) which is due to higher biomass accumulation. This has indicated that *C. ciliaris* + *S. hamata* could be a viable option for sequestering the increasing atmospheric CO_2 concentration in the rangelands under semiarid tropics.

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