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Growth, yield and photosynthesis of *Panicum maximum* and *Stylosanthes hamata* under elevated CO_2

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Abstract: *Plant height, biomass production, assimilatory functions and chlorophyll accumulation of Panicum maximum and Stylosanthes hamata in intercropping systems was influenced significantly under elevated CO_2 (600 ±50 ppm) in open top chambers (OTCs). The plant height increased by 32.0 and 49.0% over the control in P. maximum and S. hamata respectively in intercropping system under elevated CO_2 over open field grown crops (Ca). P. maximum and S. hamata produced 67 and 85% higher fresh and dry biomass respectively under elevated CO_2. Rates of photosynthesis and stomatal conductance increased in both the crop species in intercropping systems under elevated CO_2. The canopy photosynthesis (photosynthesis x leaf area index) of these crop species increased significantly under elevated CO_2 over the open grown crops. The chlorophyll a and b accumulation were also higher in the leaves of both the crop species as grown in OTC with elevated CO_2. 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 in crop biomass and soils during the three years was 21.53 Mg C/ha under elevated CO_2. The data revealed that P. maximum and S. hamata intercropping system is the potential as a sink for the increasing level of CO_2 in the atmosphere in the semi-arid tropics.*

Key words: *Biomass, Carbon sequestration, Chlorophyll, Panicum maximum, Photosynthesis, Stylosanthes hamata*
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Introduction

The response of increasing level of CO_2 on growth, photosynthesis, carbon sequestration in above and below ground biomass has been the subject of a number of studies. It has been assumed that increasing 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) and reported that growth enhanced both in 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. *Panicum maximum* 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 (600±50 ppm) on growth, morphological and physiological attributes of Guinea grass (*Panicum maximum*) and Stylo (*Stylosanthes hamata*) in intercropping system.

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Materials and Methods

Panicum maximum Jacq. 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 Chambers with elevated CO_2 (600±50 ppm) at IGFRI, Jhansi, India (25° N and 78° E, 275 msl) during 2004-2006. Thirty days old seedlings of *Panicum maximum* 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 (C_S) and intercellular CO_2 concentration (C_i) 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 hr on a clear sky day. The ratio P_N/T_R (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 *P. maximum* was recorded in two cuts at the interval of 60 days after regeneration. The stylo crop was harvested after 120 days of growth along with second cut of P. maximum. 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 hr. 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.

Results and Discussion

The plant height in *P. maximum* and *S. hamata* increased significantly under elevated CO_2 over the open field grown crops. In *P. maximum*, plant height was recorded to 212.38 cm under elevated CO_2, 181.22 cm in OTC without elevated CO_2 and 161.38 cm in open field conditions. In *S. hamata* plant height increased to 74.11 cm under elevated CO_2 over the open field grown crops

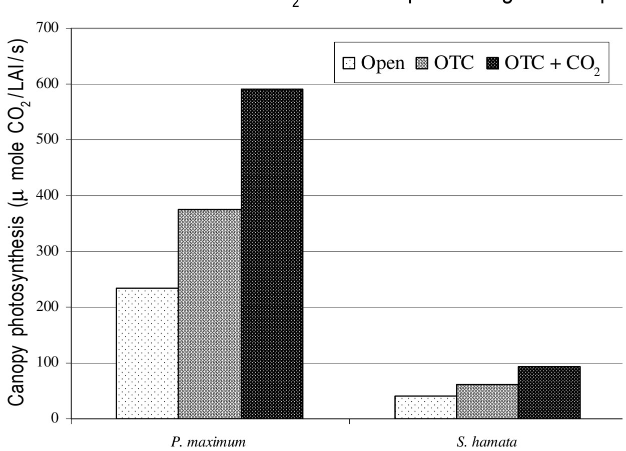

Fig. 1: Maximum probable canopy photosynthesis (photosynthesis x leaf area index) of *P. maximum* and *S. hamata* under open top chamber (OTC) with and without elevated CO_2 and in open field

(49.72 cm). On average of the three years data the plant height increased by 32.0 and 49.0% under elevated CO_2 over the control in *P. maximum* (161.38 cm) and *S. hamata* (49.72 cm) respectively in intercropping system.

Rate of photosynthesis (P_N) increased by 53% in *P. maximum* and 44% in *S. hamata* under elevated CO_2 over open field grown crops of *P. maximum* (25.45 μmol m^{-2} sec^{-1}) and *S. hamata* (21.15 μmol m^{-2} sec^{-1}) in the intercropping system (Table 1). The increase in rate of photosynthesis in *P. maximum* (C_4 plant) and *S. hamata* (C_3 plant) under elevated CO_2 exhibit the potentials of these crop species towards higher P_N at higher concentration of CO_2. The stomatal conductance (C_S) was also recorded higher under OTC with and without elevated CO_2. The increasing in stomatal conductance under elevated CO_2 exhibits that there is no effect of higher concentration of CO_2 (600±50 ppm) on functioning of stomata. The increase in P_N and C_S in one of the range grass (*C. ciliaris*) under elevated CO_2 was also reported by Bhatt *et al.* (2007). The intercellular CO_2 concentration (C_i) was recorded higher under OTC with elevated CO_2 over open field grown crops. Rate of transpiration of both the crop species increased under OTCs with or with out elevated CO_2 may be due to increase in temperature inside the chambers. P_N/T_R ratio, which indicates instant photosynthetic water use efficiency also increased significantly in *P. maximum* under elevated CO_2.

The canopy photosynthesis (Photosynthesis x leaf area index) of both the crop species increased significantly in OTC with elevated CO_2. On average of all the three years canopy photosynthesis increased by 152 in *P. maximum* and 128% in *S. hamata* under elevated CO_2 (600±50 ppm) over the open field grown crops (Fig. 1). Increase in leaf area index, and total CO_2 assimilation caused increased canopy photosynthesis which has resulted higher growth and biomass production in these crop species under long term response of elevated CO_2. Baker and Allen (2005) reported that CO_2 enrichment significantly increased canopy photosynthetic rate.

The accumulation of chlorophyll a and b in these crop species increased under elevated CO_2 as compared to the open field grown crops (Table 2). The higher accumulation of chlorophyll a and b under elevated CO_2 in both the crop species probably indicates the adaptation of these species at higher level of atmospheric CO_2. Total chlorophyll (chlorophyll a+b) was estimated higher by 1.67 fold in *P. maximum* and 1.23 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 leads to higher CO_2 assimilation resulting increased growth and biomass production. Similar to our findings, Thomas and Sean (2005) reported increase in leaf chlorophyll content under elevated CO_2.

The 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 *P. maximum* + *S. hamata* produced 4159.07 g m^{-1} fresh biomass under elevated

Table - 1: Effect of elevated CO_2 on assimilatory functions of *P. maximum* + *S. hamata* under different environmental conditions.

Treatments	P_N (µ moles m^{-2} s^{-1})		C_S (cm s^{-1})		T_R (m moles m^{-2} s^{-1})		C_i (ppm)		P_N/T_R	
	P. max.	*S. hamata*	*P. max.*	*S. hamata*	*P. max.*	*S. hamata*	*P. max.*	*S. hamata*	*P. max.*	*S. hamata*
Open	25.45	21.15	0.725	0.702	6.76	10.15	208.42	221.65	3.76	2.08
OTC	31.72	24.27	1.257	1.175	8.52	10.62	245.53	268.10	3.72	2.28
OTC + CO_2	38.95	30.47	1.403	1.452	8.97	13.05	442.45	485.23	4.34	2.33
CD at 5%	5.21	2.68	0.157	0.098	0.878	0.684	55.87	31.32	0.785	0.320

(OTC-Open Top Chambers with out elevated CO_2, OTC + CO_2-Open top Chambers with elevated CO_2 (600±50 ppm), max. = maximum

Table - 2: Effect of elevated CO_2 on photosynthetic pigments (mg g^{-1} fresh weight) of *P. maximum* + *S. hamata* under intercropping system.

Treatments	Chl a		Chl b		Chl a + b		Chl a: b	
	P. maximum	*S. hamata*	*P. maximum*	*S. hamata*	*P. maximum*	*S. hamata*	*P. maximum*	*S. hamata*
Open	1.35	1.86	0.17	0.24	1.52	2.10	7.94	7.75
OTC	1.84	1.93	0.21	0.35	2.05	2.28	8.76	5.51
OTC + CO_2	2.30	2.14	0.25	0.42	2.55	2.59	9.20	5.09
CD at 5%	0.443	NS	0.033	NS	0.194	NS	NS	0.946

(OTC-Open Top Chambers with out elevated CO_2, OTC + CO_2-Open top Chambers with elevated CO_2 (600±50 ppm), Chl = chlorophyll, NS = Non significant

Table - 3: Cumulative biomass production (g m^{-2}) in *P. maximum* + *S. hamata* under different environmental conditions during different years of growth.

Treatments	Fresh biomass production (g m^{-2})					Dry biomass production (g m^{-2})				
	1st year	2nd year	3rd year	Total	Average	1st year	2nd year	3rd year	Total	Average
Open	1479.49	2875.32	3119.59	7474.40	2491.46	453.98	802.22	797.91	2054.11	684.70
OTC	2875.63	3386.66	3395.76	9858.05	3219.35	917.84	983.49	887.38	2788.71	929.57
OTC + CO_2	3457.43	4194.98	4824.81	12477.22	4159.07	1172.95	1326.07	1303.52	3802.54	1267.51
CD at 5%	178.55	148.25	675.14	-	-	85.41	65.43	186.98	-	-

(OTC-Open Top Chambers with out elevated CO_2, OTC + CO_2-Open top Chambers with elevated CO_2 (600±50 ppm)

Table - 4: Total carbon sequestration in *P. maximum* + *S. hamata* under different environmental conditions during three years of growth.

Environmental conditions	Total dry biomass production (Mg ha^{-1}) (I+II+III Yr)	Carbon content in vegetation (Mg C ha^{-1})	Organic carbon stock in soil (Mg C ha^{-1})		Organic carbon sequestration in soil (Mg organic carbon ha^{-1}) (Mg C ha^{-1})	Total carbon sequestration (veg.+soil) (Total of 3 years)
			Initial	After 31 months		
Open	20.54	10.27	9.9	12.19	2.29	12.56
OTC	27.89	13.94	10.12	12.62	2.50	16.44
OTC+CO_2	38.02	19.01	10.80	13.32	2.52	21.53
CD at 5%	1.20	1.18	NS	NS	NS	1.006

(OTC-Open Top Chambers with out elevated CO_2, OTC + CO_2-Open top Chambers with elevated CO_2 (600±50 ppm), NS = Non significant

CO_2 which was 67% higher over the control (2491.46 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 85% under elevated CO_2 (600±50 ppm) over the crops grown in open field (684.70 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; Atkinson *et al.,* 1997). Elevated CO_2 increased leaf size, plant height and dry mass of shoot in *Trifolium alexandrinum* (Pal *et al.,* 2004).

Long term exposure of crop *P. maximum* and *S. hamata* to elevated CO_2 (600±50 ppm) in open top chambers resulted in a significant enhancement in the growth and biomass production. This increase in growth was due to the production of more photosynthates and their partitioning to different plant parts which ultimately increased the total biomass production. Increased fodder production of white clover and increased yield in rice grown under elevated carbondioxide has also been reported by Saebo and Mortensen (1995) and Uprety *et al.* (2002) respectively.

In the soil initial 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 9.90 Mg C ha^{-1} to 10.80 Mg C ha^{-1} 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 I^{st}, II^{nd} and III^{rd} yr, the range of organic carbon stock was 12.19 Mg C ha^{-1} to 13.32 Mg C ha^{-1}. 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 2.29 Mg C ha^{-1} to 2.52 Mg C ha^{-1} after 31 months of crop growth.

On total of all the three years, the carbon content in the dry biomass of these crops ranged from 10.27 Mg C ha^{-1} to 19.01 Mg C ha^{-1}. Total carbon sequestration in *P. maximum* + *S. hamata* intercropping systems was calculated by adding the values of carbon content of the biomass with organic carbon content of soil. Therefore, total carbon sequestration in *P. maximum* + *S. hamata* intercropping systems under different treatments ranged from 12.56 Mg C ha^{-1} to 21.53 Mg C ha^{-1}. Maximum carbon sequestration was calculated under elevated CO_2 (600±50 ppm) which is due to higher biomass accumulation.

The results revealed that *P. maximum* + *S. hamata* under intercropping system could be a viable option for sequestering the increasing atmospheric CO_2 concentration in the rangelands under semiarid tropics.

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