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Effects of Enhanced Level of CO_2 on Photosynthesis, Nitrogen Content and Productivity of Mungbean (*Vigna radiata* L. WILCZEK)

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Abstract

Enhanced level of CO_2 increases overall growth of crop plants, especially of C_3 species. This study was, however, initiated to quantify the effect of elevated CO_2 on changes in photosynthesis and N uptake, and their association in biomass accumulation pattern at different growth stages in mungbean (*Vigna radiata* L. WILCZEK). Mungbean (var. BUmug 1) plants were grown in pots under i) open top chamber (OTC) with 570 ± 50 ppm CO_2, ii) OTC + ambient CO_2 which was about 370 ppm and iii) open field (about 370 ppm CO_2) conditions. Elevated CO_2 increased stomatal density in leaf. Photosynthetic rate (Pn) was faster due to elevated CO_2. The difference in Pn among the treatments was very large at flowering than that during pod maturation. N content in leaf as well as in whole plant, at different growth stages, was lower with elevated CO_2. Moreover, the content was higher at vegetative stage than that at reproductive stage, irrespective of levels of CO_2. Leaf and stem dry weights were conspicuously higher with elevated CO_2; consequently, above ground biomass was also maximum in that treatment. Yield components were favored dramatically by elevated CO_2. As a result the yield advantage with elevated CO_2 was 119 and 29% of that under field and OTC + ambient CO_2 conditions, respectively.
Key words: carbon dioxide, gas exchange, mungbean productivity

Introduction

The current trend of increasing atmospheric CO_2 indicates that the level might be doubled from the present level, around 350 ppm, by the middle of this century (WATSON *et al*., 1990; HOUGHTON *et al*., 1996). The global mean temperature will also rise to 3 - 4℃ with doubling of the CO_2 concentration (REDDY *et al*., 1995). Such a change of the atmosphere will obviously bring a shift in overall agriculture globally.

Enhanced level of CO_2 increases productivity, from 10 to 40%, of different food crops (KIMBALL 1983; MITCHELL *et al*., 1993; WEIGEL *et al*., 1994; HAMID *et al*., 2003). The variation in the range of productivity among the crop species attributed to differences in

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photosynthetic performance and sink strength. C_3 species responds more to high level of CO_2 than C_4 species. This is largely because the oxygenase activity of CO_2 fixing enzyme, ribulose biphosphate carboxylase/ oxygenase (Rubisco), of C_3 plants reduced at a high level of CO_2. Whereas, the CO_2 fixing process of C_4 plants does not competitively inhibited by CO_2 (PEARCY and BJÖRKMAN 1983).

Mungbean (*Vigna radiata* L. WILCZEK) is a tropical legume, extensively grown in diverse agro-climatic conditions of Asia and Australia. As a C_3 legume, mungbean also responded positively to enhanced CO_2 (UPRETY *et al.*, 1996). The positive response of mungbean was related to high water use efficiency, greater photosynthesis and higher nutrient use efficiency. However, insufficient information exists on a stage dependent pattern of biomass accumulation and gas exchange activities. To develop a practical crop performance model of mungbean, under changing atmospheric CO_2 conditions, more precise information on each plant character is required. The present study was designed to quantify the pattern of biomass accumulation, nitrogen uptake and gas exchange activities at different growth stages of mungbean, exposed to long term enhanced level of CO_2.

Materials and Methods

The experiment was conducted at the farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Bangladesh during March- May, 2003. The soil used in this experiment was loamy in texture, with pH 7.10 and 0.12% total nitrogen. The amount of available phosphorus and exchangeable potassium was 0.10 and 0.30mg 100^{-1} g dry soil, respectively.

Mungbean (var. BUmug 1) plants were grown in pots of 24cm in diameter and 27cm in height filled up with 12kg air-dried soils. Three growing conditions were created, viz. i) open top chamber (OTC) with elevated CO_2 (570 ± 50 ppm), ii) OTC with ambient CO_2 (about 370 ppm) and iii) open field (about 370 ppm) near the OTC.

Details of the construction and operation of open top chamber (OTC) can be found elsewhere (LEADLEY and DRAKE 1993; UPRETY 1998). It is made of an iron frame of 3m in diameter and 3m in height. It was installed on the ground and covered with transparent polyvinyl chloride sheet. The top of the chamber was open to ensure near natural conditions. The CO_2 gas was supplied to the chamber from gas cylinder using a manifold, gas regulator, pressure gauge and underground pipeline for using natural air with the help of a blower. The air blower, 30cm diameter, thoroughly mixed the supplied CO_2 gas with atmospheric air and blew to the chamber.

A fertilizer dose of 90kg urea, 130kg triple super phosphate (TSP) and 70kg muriate of potash (MP) per hectare (recommended dose in Bangladesh) corresponding to 540mg urea, 780mg TSP and 420mg MP per pot were used. Entire amount of TSP and MP, and one half of urea were mixed into soil before sowing. The other half of urea was applied 3 weeks after sowing. Seeds were soaked in water for six hours and then four bold seeds were sown in each pot. Thinning was done at appearance of the 1st trifoliate leaf to keep two uniform and healthy plants in each pot. Weeding and other plant protection measures were done as and when those were necessary.

Stomatal density was measured at flowering stage from fully expanded uppermost leaf. In a preliminary study we noticed that number of stomata in abaxial side of leaf was higher but well correlated with that in adaxial side. Therefore, we measured the stomatal frequency only from the adaxial side. Cover slips of slide were attached to leaf with super glue for getting stomatal impression. After 15 minutes, the cover slips were removed. The number of stomatal impressions was counted from 20 microscopic fields per genotype per treatment under 40X magnification. Since the photosynthesis at reproductive stage (current photosynthesis) influences greatly on grain yield, we measured leaf photosynthetic rate (Pn) during flowering and pod maturation at 11:00 am in clear days with a portable photosynthesis system (LICOR 6200, Lincoln, Nebraska). Pn was measured from the uppermost fully developed leaves of four plants from each growing condition. N content at different growth stages were estimated by colorimetric method following LINDER (1944).

Plants were sampled at vegetative (four weeks after sowing), flowering and maturity to determine matter partitioning into different components of mungbean plant. Reproductive organs were considered during measurement of above ground biomass. Yield and yield components were recorded from six plants per treatment.

The data recorded on different parameters were statistically analyzed with help of "MSTAT" program. Differences between the treatment means were compared by least significant difference (LSD) test at 5% level of significance after performing ANOVA.

Results and Discussion

Elevated CO_2 increased stomatal density to a great extent (Table 1). Leaves developed under elevated CO_2 had 41 and 32% more stomata than those developed under OTC + ambient and field conditions. During microscopic study, it was noticed that epidermal cells of the leaves under elevated CO_2 were smaller but grater in number than those under field and OTC + ambient CO_2 conditions. High stomatal frequency with elevated CO_2 could be due to higher number of cells but smaller in size, although cell size was not recorded in this study. In general photosynthetic rate (Pn) was faster during flowering than that during pod maturation, under both OTC conditions (Table 1). The Pn was, however, not changed much under field conditions. During flowering stage, the Pn at elevated CO_2 was 46 and 104% higher, while that during pod maturation was 23 and 14 % higher than that measured at OTC + ambient CO_2 and field conditions, respectively. Thus, the difference in the Pn, among the treatments, was much higher at flowering than that at later stage. Higher Pn under elevated CO_2 in C_3 plants was also reported by ZISKA and TERAMURA (1992), and UPRETY and MAHALAXMI (2000). According to PEARCY and BJÖRKMAN (1983), the increase in Pn in C_3 plants under elevated CO_2 was related to CO_2 induced reduction in oxygenase activity of Rubisco, the primarily CO_2 fixing enzyme in C_3 species. Higher photosynthesis during flowering and the subsequent decline during pod maturation could be related to sink demand for photosynthates. At flowering stage, the demand for photosynthates increases due to onset of pod formation as well as continuation of vegetative growth. During pod maturation, however, the demand decreases due to slow down of growth processes, and the Pn may decline due to feed back effect (DELGADO *et al.*, 1994). The higher number of stomata under elevated CO_2 might have also contributed for higher Pn under such conditions, as stomata regulates gas exchange activity in plants.

Irrespective of levels of CO_2, higher leaf N was observed at vegetative stage and the minimum at final harvest. N in leaf, under elevated CO_2, was 14, 26 and 12% lower at vegetative, flowering and maturity, respectively from that under field conditions. The corresponding reduction under OTC + ambient CO_2 was 18, 26 and 17%, respectively. Therefore, the difference in leaf N among the treatments was much higher at flowering. The effect of elevated CO_2 on total N content in plant was more or less similar to that measured in leaf. Perhaps, the low percentage of N under elevated CO_2 was due to dilution effect for high N use efficiency under such conditions (high biomass per unit N). *Brassica* plants also showed reduction in N content by 30% due to enhanced CO_2 (UPRETY and MAHALAXMI 2000). According to HOCKING and MAYER (1990) elevated CO_2 could cause increased biomass per unit uptake of N, even N is limiting in the substrate.

Table 1. Effects of elevated CO_2 on stomatal frequency and photosynthesis in mungbean.

Treatments	No. of stomata mm^{-2}	Photosynthesis ($\mu mol\ m^{-2}s^{-1}$)	
		Flowering	Pod maturation
OTC + elevated CO_2	20.8	30.0	17.6
OTC + ambient CO_2	14.8	20.5	14.3
Field conditions	15.8	14.7	15.5
LSD (0.05)	1.96	2.95	1.59
CV (%)	5.93	6.59	5.86

Notes: Elevated CO_2 level was 570±50 ppm; CO_2 under OTC + ambient and field conditions was about 370 ppm.

Table 2. Effects of elevated CO_2 on leaf N and total N at various growth stages in mungbean.

Treatment	Leaf N (%)			Total N (%)		
	Vegetative	Flowering	Maturity	Vegetative	Flowering	Maturity
OTC+elevated CO_2	3.1	2.3	1.5	2.3	1.4	0.8
OTC+ambient CO_2	3.8	3.1	1.8	2.6	2.4	1.0
Field conditions	3.6	3.1	1.7	2.5	2.1	0.9
LSD (0.05)	0.11	0.10	0.11	0.08	0.20	0.08
CV (%)	5.7	5.9	6.6	6.3	5.3	3.4

Notes: Elevated CO_2 level was 570 ± 50 ppm; CO_2 under OTC + ambient and field conditions was about 370 ppm.

Leaf dry matter increased with ontogeny (Table 3). Elevated CO_2 increased leaf dry mass by 74, 40 and 50% compared to that under field conditions, at vegetative, reproductive and maturity stages, respectively. The corresponding increase was 51, 16 and 14%, respectively under OTC + ambient CO_2 conditions. Similarly, stem dry mass under elevated CO_2 was 91, 11 and 14% higher at vegetative, flowering and maturity, respectively than that under field conditions. The corresponding stem biomass was 62, 7 and 7% higher than that under OTC + ambient CO_2 conditions, respectively. Above ground biomass also showed a similar response to leaf and stem mass. The large difference in biomass accumulation among different growth stages was largely due to a very fast growth of plants at early stage, brought about by elevated CO_2. The higher Pn due elevated CO_2 presumably contributed for higher biomass production under such conditions. According to PAL *et al.*, (1997) higher dry matter accumulation in stem and leaves under elevated CO_2 was caused by higher photosynthesis under such conditions. Elevated CO_2 induced increase in biomass was also observed in cotton and soybean (KIMBALL 1983).

Table 3. Effects of elevated CO_2 on weights of leaf, stem and above ground biomass at different growth stages in mungbean.

Treatments	Leaf dry weight (g plant^{-1})			Stem dry weight (g plant^{-1})			Above ground biomass (g plant^{-1})		
	Vegetative	Flowering	Maturity	Vegetative	Flowering	Maturity	Vegetative	Flowering	Maturity
OTC+elevated CO_2	1.22	3.53	4.24	0.42	1.18	5.40	1.64	5.75	23.80
OTC+ambient CO_2	0.81	3.04	3.71	0.26	1.10	5.03	1.07	5.14	20.08
Field conditions	0.07	2.52	2.82	0.22	1.06	4.75	0.92	4.49	15.10
LSD (0.05)	0.15	0.22	0.33	0.08	2.07	NS	0.174	0.272	1.637
CV (%)	3.5	4.32	3.52	5.69	5.36	8.69	10.81	4.45	6.71

Notes: Elevated CO_2 level was 570 ± 50 ppm; CO_2 under OTC + ambient and field conditions was about 370 ppm.

Table 4. Effects of elevated CO_2 on plant height, yield components and grain yield of mungbean.

Treatments	Plant height (cm)	Pods plant^{-1}	Seeds pod^{-1}	100-seed weight (g)	Yield plant^{-1} (g)
OTC + elevated CO_2	65.6	26.9	9.00	5.32	11.96
OTC + ambient CO_2	58.3	24.3	8.10	4.85	9.26
Field conditions	52.5	20.5	5.90	3.66	5.45
LSD (0.05)	5.68	2.1	0.85	0.45	1.27
CV (%)	6.8	6.13	6.3	4.64	7.93

Notes: Elevated CO_2 level was 570 ± 50 ppm; CO_2 under OTC + ambient and field conditions was about 370 ppm.

Elevated CO_2 increased plant height by 13 and 25% compared to that under OTC + ambient CO_2 and field conditions, respectively (Table 4). Number of pods per plant was much higher under elevated CO_2 than that observed under OTC + ambient CO_2 (11%) and field conditions (31%). Elevated CO_2 also increased number of seeds per pod and seed size (100- grain weight) by 53 and 45%, respectively compared to those measured under field conditions. The corresponding increase was 11 and 10%, respectively compared to that under OTC + ambient CO_2 conditions. Naturally the better off yield components in plants with elevated CO_2 increased the grain yield conspicuously by 119 and 29% compared to that under field, and OTC + ambient CO_2 conditions, respectively. The faster rate of current photosynthesis (photosynthesis at reproductive stage) under elevated CO_2 might have contributed appreciably for higher grain yield. However, the large difference in Pn among treatments during flowering might have contributed mostly to the difference in grain yield of mungbean under different growing conditions.

In conclusion, elevated CO_2 enhanced greatly the mungbean productivity. The better performance of mungbean plant due to high level of CO_2 was supported by the faster rate of photosynthesis, especially at flowering stage. Elevated CO_2 also increased the productivity of mungbean per unit amount of N. Perhaps the vigorous growth of mungbean plant caused by elevated CO_2 demands for more nitrogen application than that recommended for field conditions in Bangladesh.

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